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ON THE

USE OF HOT AIR

IN THE

IRON WORKS OF ENGLAND AND SCOTLAND.

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ENGLAND AND SCOTLAND.

TRANSLATED FROM A REPORT, MADE TO THE DIRECTOR GENERAL OF MINES IN FRANCE, BY M. DUFRENOY, IN 1834.

LONDON:

J. MURRAY, ALBEMARLE STREET.

MDCCCXXXVI.

Bristol:

CHILCOTT, WINE STREET.

REPORT

TO THE DIRECTOR GENERAL OF BRIDGES, ROADS, AND MINES, UPON THE USE OF HOT AIR IN THE IRON WORKS OF SCOTLAND AND ENGLAND.[1]

SOME experiments made in a common smith's fire, by Mr. Neilson, (director of the gas works of Glasgow,) led him to think that it might be advantageous to maintain combustion, by means

[1] We know that to produce the high temperature necessary for the fusion of iron ore, it is requisite that the combustion should be excited by a very strong current of air. Until lately the air drawn from the atmosphere by the blowing machine was thrown at once into the blast furnaces. For the last three years there has been an idea of blowing the furnaces by air previously heated. This change in the temperature of the air has produced in the Scotch iron works a vast saving of fuel, and an amelioration in the quality of the pigs. From some attempts of the same kind, made in France and in the forges on the banks of the Rhine, the results have been various and inconclusive.

The director general of bridges, roads, and mines, desiring to elucidate a point which is so important in the manufacture of iron, deputed Mr. Voltz to inquire into the trials made at Wurtemburg, and commissioned me to investigate the processes used in England and Scotland. This report contains the result of my observations during this mission.

of air previously heated. He communicated his ideas to Mr. Macintosh, long known in the scientific world for his spirit of invention.[2] They undertook, in concert with Mr. Wilson, one of the proprietors of the Clyde works, a series of experiments at that establishment, in order to throw some light upon this important question. In the first experiment the air was heated in a kind of rectangular box of sheet iron, ten feet long, four high, and three wide, similar to the boilers of steam engines. The air proceeding from the blowing machine, was introduced into this space, where it was heated, previous to being conveyed into the blast furnace. Notwithstanding the imperfection of this process, which did not admit of the air being heated above 200° Fahr., it became immediately apparent that Mr. Neilson's idea was destined to produce a revolution in the manufacture of iron. As, however, this apparatus did not long resist the action of heat and oxidation, and as it would have been expensive to renew it, they substituted a cast iron tube, having in the centre a swelling similar to the bulb of a thermometer. This second apparatus was a considerable improvement; it

[2] Mr. Macintosh is the inventor of a process for the fabrication of steel, by means of carbonated hydrogen gas, produced from the distillation of coal.

lasted much longer, and allowed the temperature of the air to be raised to 280° Fahr. This increase of temperature, although trifling, produced a remarkable saving of fuel.

Messrs. Neilson, Macintosh, and Wilson, then saw the advantage which would arise from the elevation of the temperature of the air several hundred degrees. They abandoned the heating tube and constructed a new apparatus, having a long range of pipes, heated at several points in their length. By means of this new construction, the temperature of the air was carried to 612° Fahr. which is a greater heat than that of molten lead, and at which point this metal volatilizes.

Although this temperature was much below what is necessary for fusing pig iron, (which is reckoned at 1500°,) it produced a considerable saving in the consumption of fuel. Another important advantage was obtained from it, that of being able to use raw coal instead of coke, without any derangement of the work of the furnace: on the contrary, the quality of the metal was improved, and a furnace, which, when charged with coke, produced only about half No. 1.[3] and half

[3] No. 1. pig iron is the best for foundry purposes, and is often called dark grey. No. 2. though soft, is sometimes used for making bar iron.

No. 2. pig iron, gave a much larger proportion of No. 1. after the substitution of raw coal. Besides this, the consumption of limestone was considerably diminished. This last circumstance is probably owing to the increased temperature of the furnace, which renders it unnecessary to employ so large a quantity of fluxing matter, in order to vitrify the earthy particles which accompany the mineral. To this elevation of temperature we may also probably attribute the power of using coal instead of coke.

To give a better idea of the progressive saving made at the Clyde works, the proportionate quantity of coal and limestone consumed in each of three several experiments is here subjoined.

In 1829, the combustion being produced by cold air,—

	ton.	cwt.	ton.	cwt.
Coal: 1. For fusion, 3 tons of coke, corresponding with ..	6	13		
2. For the blowing engine	1	0—	7	13
Limestone				$10\frac{1}{2}$

In 1831, the furnaces being blown with air, heated to 450° Fahr., coke being still used for the fusion of minerals,—

	ton. cwt.	ton. cwt.
Coal: 1. For fusion, 1 ton 18 cwt. of coke, corresponding with	4 6	
2. For the hot air apparatus	5	
3. For the blowing machine	7—4	18
Limestone		9

In July, 1833, the temperature of the air was raised to 612° Fahr. and the fusion was entirely effected by raw coal.

	ton. cwt.	ton. cwt.
Coal: 1. For fusion	2 0	
2. For the hot air apparatus	8	
3. For the blowing engine..	11—2	19
Limestone		7

At this period the use of hot air had increased the make of the furnaces by more than one third, and had consequently produced a great saving of expense in the article of labour. The quantity of blast necessary for the furnaces was also sensibly diminished; as a blowing engine of seventy-horse power, which, in 1829, served only for three blast furnaces, was sufficient for the supply of four.

On comparing these several results, we find that the saving of fuel is in proportion to the temperature to which the air is raised. As for the actual saving, it varies in every work according to the nature of the coal, and the care with which the operation is conducted.

Notwithstanding the complete success of these experiments, the introduction of heated air into iron works has had many difficulties to encounter. It has been necessary to overcome, not only the force of habit, but the general prejudice that coal is sulphureous; and that its conversion into coke is not only favourable to combustion in blast furnaces, but is even indispensable in the manufacture of pig iron of good quality.

This process, though it has been four years in use in the works near Glasgow, (which it has rescued from certain ruin,) has scarcely passed the borders of Scotland; the miraculous advantages, however, which it has produced, are beginning to triumph over these prejudices, and gradually to extend its use into the different English iron districts. There are one-and-twenty works, containing altogether sixty-seven blast furnaces in which hot air is used.[4] The pig iron

[4]
In Scotland		6
Flintshire		1
Derbyshire		3
Newcastle-upon-Tyne (Northumberland)		2
Newcastle-under-Line (Staffordshire)		2
Wednesbury...1	Staffordshire	5
Dudley.........1		
Now building 3		
Pontipool		2
	Total	21

made in these furnaces is generally No. 1., and is fit for making the most delicate castings. This process is equally applicable to pigs intended for the manufacture of bar iron; as in order to obtain this quality of iron, it is only necessary to alter the proportion of fuel and mineral. In the forges of the Tyne iron works, near Newcastle, and of Codnor Park, near Derby, pigs made in furnaces blown by hot air are alone used in the manufacture of bar iron.

Raw coal has been substituted for coke in most of the establishments I have mentioned. In some, where this plan has not yet been adopted, (as at the Monkland iron works, near Glasgow,) I have been informed that the temperature of the air is not sufficiently elevated to dispense with the use of coke. In some others, (as near Newcastle,) the extremely bituminous quality of the coal appears to be an obstacle to the use of it in its natural state.

The hot air system is not yet introduced into the great works of Merthyr Tidfil, in Wales. Its adoption is there retarded by the comparatively small consumption of coal, as I shall show at the end of this report, and by the high price required for the use of the patent; but I have no doubt that the process would, in that country, be equally productive of a considerable saving in the consumption of fuel.

In order that the advantages which result from hot air may be duly appreciated, I will give a statistical review of the principal establishments which I visited ; I will describe those apparatus which present varieties; and compare the consumption and expense incurred in the manufacture of a ton of pig iron before the introduction of hot air, with what it requires in the same works under the new system. This description may appear tedious, but on a question of so much importance to those engaged in the manufacture of iron, nothing ought to be omitted which may tend to elucidate the subject. I will afterwards enter into some detail upon the different sorts of coal used in these works, and also upon the expense of manufacturing pig iron in Wales; and will conclude this report with a summary of the principal experiments made for the introduction of the hot air process into the French iron works.

Previous to entering upon this description, I ought to acknowledge the gratitude I feel towards the proprietors of the works I have visited, almost all of whom have afforded me the means of examining their establishments minutely, proving thereby that the only rivalry existing between France and England, is in the desire of improvement.

Works in the Neighbourhood of Glasgow.

The district of Glasgow is occupied by an immense coal field, one of the richest in Great Britain for its extent, and for the number of beds of coal which it contains. This basin is also very remarkable for the abundance of iron ore, which exists in detached masses in the argillaceous shale of the coal field, and also in regular veins, which are often of considerable extent. Those veins of coal which belong to the lowest parts of the coal field, alternate with strata of mountain limestone; so that in the same district are found coal, iron ore, limestone, and even (almost always) fireclay, which is necessary for the construction of blast furnaces. These circumstances, so advantageous to the establishment of iron works, were nearly neutralized by the enormous loss which the Glasgow coal sustained in coking, as well as by the lightness of the cokes which it produced. The result was, that a much larger quantity of fuel was required to make a ton of pig iron in Scotland, than in any other part of Great Britain. Since the introduction of the hot air process, this is no longer the case; and the Scotch iron works are able to compete even with those of Wales.

The Clyde iron works are, as I have already

stated, the first into which this process was introduced. The apparatus now in use there, is composed of (fig. 1. and 2.) a double row of horizontal pipes, *a, a,* one hundred and fifty feet in length; these pipes are nineteen inches in diameter, and one and a half thick. The exterior range terminates as high as the middle of the furnace, and the air divides itself into two parts, so as to carry an equal quantity to each tuyere: valves placed at E regulate the distribution of the blast, and serve also to stop it when required. In this range of one hundred and fifty feet, the pipes pass through five furnaces (F), two of which are placed near the tuyeres, in order that the air may not have time to cool before entering the furnace. The fig. 1. and 2. give an exact representation of the form and position of these five furnaces: they are connected with one another by a flue of brick, which surrounds the pipes. By means of this arrangement, the flame and smoke which escape from the furnaces circulate around the pipes, and heat them through their whole length. To prevent damage to those parts of the pipes which are immediately exposed to the action of the fire, they are surrounded by a coating of fire bricks of the length of the furnaces. In the first apparatus of this kind which was constructed, the pipes were placed one within

Clyde Apparatus.

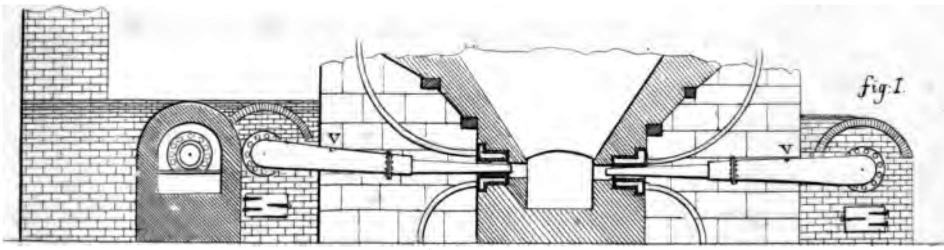


fig: I.

Section of the plan at A.B.

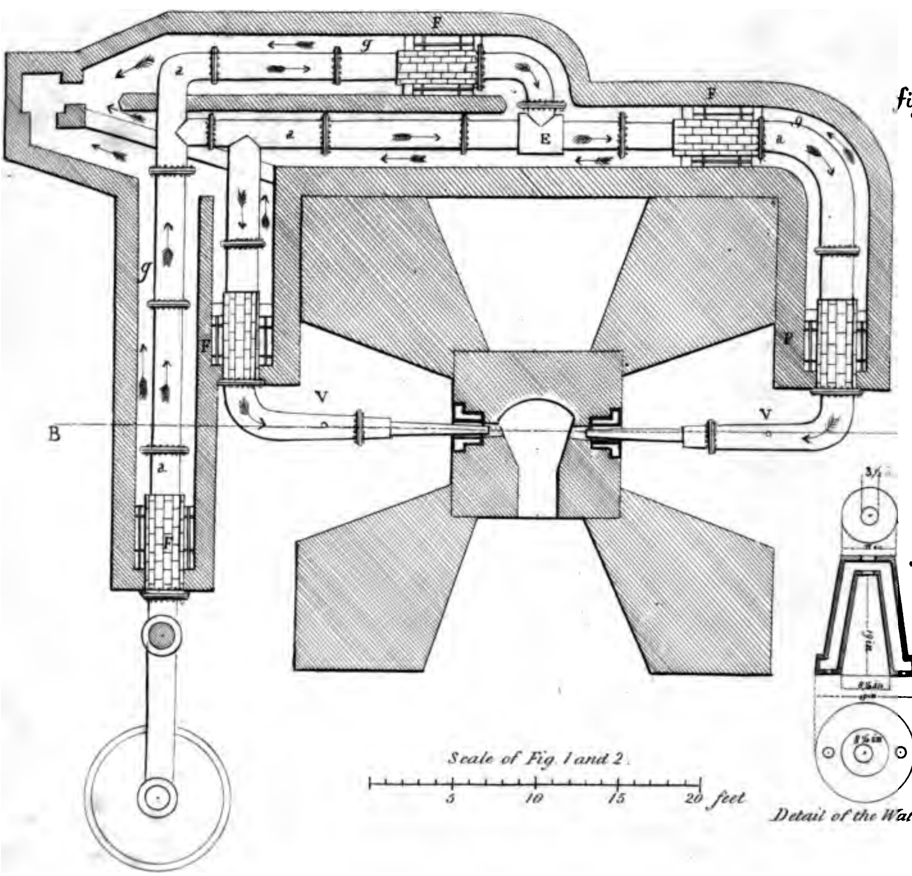


fig: 2.

fig 8

Detail of the Water tuy

al.

Jan. 1836.

the other, so that they might have play, and that no rupture should ensue from expansion. This ingenious arrangement has been abandoned, because a considerable body of air was lost at the joints; and, as it was also observed that a considerable loss took place at the junctions of the pipes when joined with bolts and screws, a plan was adopted of covering these junctions with a ring of cast iron, which made the pipes more durable. At the time I visited the Clyde works, this apparatus had not required repairs for five months.

In the tuyere pipe a small hole is made, by means of which the heat of the air may be ascertained at any moment. This precaution is indispensable, it being essential to the beneficial use of hot air, that it be kept to a high and uniform temperature. With this apparatus the air is raised to 612° Fahr. which is a greater heat, by several degrees, than is necessary for the fusion of lead.

Two of the four blast furnaces at the Clyde works, have an apparatus similar to that which I have described; and as the situation of the other two does not admit of the pipes being disposed in the same manner, they are doubled over one another.

Furnaces blown with hot air do not require

any extraordinary management; the operation of working them is exactly the same as it was before the introduction of this process, the only difference consisting in the substitution of raw coal[5] for coke. This substitution did not immediately follow the adoption of the new process. It was not until long after, and when the temperature of the air was raised above the fusion of lead, that this great improvement took place; and it was from that period that the expense diminished in so large a proportion. It appears, or at least the idea generally prevails in Scotland, that some certain qualities of coal can only be employed when the air is strongly heated: I have already mentioned that in the Monkland iron works, where the temperature is only carried to from 460° to 490° Fahr. coke is still in use.

The descent of the minerals in the furnace is very regular; they are charged at nearly equal distances of time, the sinking at the tunnel head being the filler's only guide. As the produce of the uncalcined minerals varies from twenty-two

[5] [The introduction of coal instead of coke, is not at all dependent on the use of hot air, as in many works where hot air is used, coke is still necessary; and in some others raw coal is used in a blast furnace, without hot air. This is the case at Dowlais, where Mr. Guest, some years since, substituted coal for coke.—*Note by the Translator.*]

to thirty-four per cent. the composition of the charges ought to follow these variations. At the time of my visit at this establishment, the average of the minerals was forty-four per cent. after calcination, and the charges were composed of—

660 lbs. of coal
520 „ „ calcined ore
100 „ „ limestone.

Forty of these charges were usually put in in twenty-four hours. During two days that I attended to the progress of the Clyde works, the number of charges was,—

July 4,	from	6 A.M.	to 6 P.M.	38
	„	6 P.M.	„ 6 A.M.	39
6,	„	6 A.M.	„ 6 P.M.	37
	„	6 P.M.	„ 6 A.M.	40

The produce of the furnace in the four sows, was 4 tons 8 cwt., 4 tons 9 cwt., 4 tons 6 cwt., and 4 tons 12 cwt., which makes 17 tons 15 cwt. to 154 charges, or 8 tons 17½ cwt. in 24 hours.

It appears from these data that, on an average, a ton of pig iron requires 4856 lbs. of coal, or 2 tons 8½ cwt. The consumption of the hot air apparatus is 8 cwt. to the ton of pig iron, which raises the total quantity to 2 tons 16½ cwt.—say about 2¾ tons to the ton of pig iron.

The castings take place every twelve hours. The iron obtained is generally a mixture of No. 1. and No. 2.; that which first issues from the hearth is No. 1. The two sorts of pigs are known by the manner in which they flow, and above all, by the disposition of the streaks which mark the surface of the metal as it cools. The tuyeres are hermetically closed with clay; and, as the ordinary tuyeres would not resist the high temperature to which they are exposed, water tuyeres have been substituted for them, similar to those used in refineries. Fig. 3. represents the tuyeres in use at Clyde; they are of cast iron, and their duration is very uncertain—on an average five to six months.

The tuyeres are stopped up, that the cold air may not enter the furnaces. This arrangement is not at all inconvenient, because the blast passing through the tuyeres is so hot, that no scoria or snuff attaches to them; and therefore it is hardly ever necessary to touch them. The temperature at this part of the furnace is of a brilliant white; nevertheless, there are scarcely any sparks produced by the oxidation of the iron; and the small globules which fall have a black centre, which shows that the pig iron is covered with a thin layer of cinder, in the state of fusion.

The flame which escapes from the tunnel head

is of a bright red, whilst that of furnaces supplied with coke, and blown with cold air, is of a yellowish hue. The difference of colours is almost as remarkable as that which exists between flame given out by the respective solutions of strontia and barytes in alcohol.

The pressure of the blast in the air receiver is 2½ lbs. (or five inches of mercury,) to the inch. It is apparently very much the same near the tuyere; but the blast guage which indicates it is subject to great variations. This pressure was formerly 3 lbs. The size of the muzzle of the tuyere is three inches; it was two and a half when the furnace was blown with cold air. The quantity of blast thrown into the furnace is diminished; the blowing engine of seventy-horse power, which used to blow only three furnaces, now blows four with great facility. According to the dimensions of the blowing cylinder,[6] the quantity of blast was

6 The power necessary for blowing a furnace, has not diminished in the same proportion as the quantity of air required for sustaining combustion. The friction of the blast in the pipes of the apparatus used for heating the air, opposes a resistance to its motion, which requires an increase in the power of the blowing machine. The expansion of the air, the volume of which, at 322° centigrade, (nearly double its volume at 10°,) would be a retarding cause more powerful than the friction, if the increased area of the discharging pipes did not compensate for it. A calculation of one tenth is made for the force necessary to overcome the

formerly 2827 cubic feet per minute for each furnace, when blown by cold air, and is now only 2120 cubic feet.

The furnaces at the Clyde works have not been altered since the introduction of hot air; they had been in blast a long time when this new method was adopted; one of them has been at work upwards of seven years, and, from the regularity of its progress, it will probably last seven years longer.

At the commencement of this report, I stated the savings of coal and limestone which had been effected by the use of hot air in the Clyde works; I, nevertheless, think it may be useful, for the sake of showing the correctness of these calculations, to transcribe an abstract of the expenses of making pig iron, during one month, with cold air; and during another month, with hot air. I have founded these calculations upon returns

friction; but, as in most of the English works the diminution of the blast by the use of hot air is at least one fourth, it follows that the power required for the blowing machine for hot air is less than that for cold air.

The cylinder of the blowing machine is 80 inch. diameter and 10 feet long; the stroke 7 feet 6 inch.; the number of strokes 18 per minute. It blows up and down; the pressure of the air, 2½ lbs. The steam cylinder is 40 inch.; the same stroke of 7 feet 6 inch.; and the pressure of steam in the boiler, 24 inch. 9 lines.

which have been very kindly communicated to me.

Consumption and produce of three blast furnaces blown by cold air, and using coke, during the month of February, 1829.

	Coke.	Mine.	Limestone	Pig Iron. No. 1.	Pig Iron. No. 2.	Pig Iron. No. 3.	Castings.	Total.
	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.
1st Week ...	386 0	227 9	68 2	72 13	32 13	18 13	1 13	125 12
2nd Week...	411 10	242 11	72 11	51 19	37 11	47 2	6	136 19
3rd Week...	401 0	231 16	70 18	44 16	48 2	38 7	3	131 8
4th Week .[7]	301 10	177 13	53 6	53 0	27 9	25 3	0	105 12
	1500 0	879 9	264 17	222 8	145 15	129 5	2 2	499 11

7 To this must be added the consumption of the blowing engine, which was on an average one ton of small coal to the ton of pig iron.

Consumption and produce of four furnaces using raw coal, and blown by hot air during the month of February, 1833.

	Raw Coal.		Mine.		Limestone		Pig Iron. No. 1.		Pig Iron. No. 2.		Pig Iron. No. 3.		Castings.	Total.	
	ton.	cwt.	ton.	cwt.	ton.	cwt.	ton.	cwt.	ton.	cwt.	ton.	cwt.		tou.	cwt.
1st Week...	516	15	490	7	91	16	81	4	28	15	155	3	...	265	2
2nd Week...	514	0	491	6	91	7	48	8	46	15	161	18	...	257	1
3rd Week...	521	15	486	8	91	8	94	12	60	0	109	8	...	264	0
4th Week .[8]	470	10	434	12	81	18	75	2	47	0	102	1	...	224	3
	2023	0	1902	13	356	9	299	6	182	10	528	10		1010	6

[8] Consumption of the blowing engine, 11 cwt. to a ton of pig iron on an average. The apparatus for heating the air, 8 cwt. per ton.

These tables shew that the consumption in making one ton of pig iron was—

In 1829, with cold air and coke.	ton.	cwt.	ton.	cwt.	In 1833, with air heated to 322° 2 centig. and with raw coal.	ton.	cwt.	ton.	cwt.
1. Coal, for fusion, 3 ton of coke corresponding to coal.....................	6	15			Raw Coal.....................	2	0		
For the blowing engine[9]	1	0—	7	15	,, ,, ...		11		
For the heating apparatus			...		,, ,, ...		8—	2	19
2. Calcined ore, 3523 lbs. Its average is 57 per cent.			1	15	3780 lbs. on an average 56 per cent.			1	18
3. Limestone, 1056 lbs. ...				10½	704 lbs.				7
The daily produce of the furnaces was, about									
11904			6	0	18035 lbs.			9	0

9 The blast engine consumes 20 tons of small coal per diem; this coal costs only 1*s.* 8*d.* per ton.

The daily produce of iron at the Clyde iron

works being raised from 6 to 9 tons, by the introduction of hot air, it has occasioned a saving, in consumption of fuel, in the expenses of labour, and in general charges.

The following table shews the price of manufacturing pig iron at these two periods.

Cost price of a ton of pig iron at the Clyde iron works.

Materials used.	In 1829, with cold air.					In 1833, with hot air.				
	ton.	cwt.	£	s.	d.	ton.	cwt.	£	s.	d.
Coal for fusion, at 5s. per ton	6	13	1	13	3	2	0		10	0
for the blowing machine, at 1s. 8d. per ton	2	0		3	6		11			11
for the heating apparatus	...			...			8			8
Calcined ore, at 12s. per ton[10]	1	15	1	1	0	1	18	1	2	9
Limestone, at 7s.		10		3	6	...			3	6
Labour, at 10s.	...			10	0	...			10	0
General charges, interests of capital, 6s.	...			6	0	...			6	0
	Total......		£3	17	3			£2	13	10

10 This mineral is very rich, the average produce of the iron mines of the Glasgow coal basin, is 44 per cent. after calcination; in this state it costs from 8s. 6d. to 9s. per ton. The cost of the mineral will, therefore, be very nearly as stated in the table.

Calder Iron Works.—In these works, situated three miles from Glasgow, upon the road to Edinburgh, hot air has been used for the last three years; two of the furnaces have an apparatus similar to those at the Clyde works; but in others, the air is heated by means of small pipes.

This apparatus is composed of two large horizontal pipes, 10 feet long, 9 inch. interior diameter, and $1\frac{1}{2}$ inch thick. Nine small pipes of 6 inch. exterior, and 3 inch. interior diameter, doubling upon each other like syphons, are placed vertically upon the large pipes, into which they are inserted. This range of pipes is placed in a rectangular furnace, 10 feet long by 3 feet wide, and from 12 to 15 feet high. The joints being liable to injury, care is taken to protect them from the immediate action of the fire. The joints of the large pipes are placed outside the furnace; and the junctions of the small pipes with the large ones are protected by brick work, which runs all along the large pipes. The flame is carried through a longitudinal[11] opening, traversing the whole length of the furnace; it then spreads between the pipes, surrounding them

[11] The situation of the blast furnances at Calder, has prevented this part of the furnace from being made larger. It would be preferable to procure a large vent for the flame, which might be obtained by opening the angles of the small pipes.

on all sides, and enters the chimney by means of openings into it.

With this apparatus the temperature of the air is raised above 612° Fahr., as in the case of the Clyde works; the consumption of coal is 7 cwt. to the ton of pig iron produced.

This apparatus appears to me to be preferable to that at the Clyde works; it occupies less space. It is true that the angles formed by the small pipes, must occasion some friction of the air which passes through them; but this circumstance appears to have but a slight influence on its motion. The power of the blowing engine is not greater than that at the Clyde works. The pressure of the blast is 2¾ lbs. to the square inch.

The expense of construction is very small. The greatest part consisting of cast iron, we may calculate the construction of the furnace at about £32, and there may be 7 tons of cast iron in it, viz.—1¼ tons for the two great pipes, and about 5½ for the nine small ones.

Estimating a ton of iron cast into pipes at about £5 : 8*s.*, which is the average in works using coal, the expense of the apparatus will be for each tuyere ;—

Brick work	£20	0	0
Iron work for the furnace	12	0	0
Cast iron pipes	33	8	0

Thus the total cost is about £130 16*s.* per blast furnace. At Calder they reckon £35 to each tuyere. The apparatus used at the Clyde works is much more expensive; we may reckon that it requires from 17 to 18 tons of cast iron, and the cost of the masonry is about twelve times as much as at the Clyde.

I will not recite the workings of the blast furnaces at Calder, as they present the same features as those of the Clyde works; but in order to show the successive progress of the introduction of hot air, I shall point out,—

1. The consumption and the yield of a furnace at Calder, blown by cold blast, and consuming coke.

2. The expenses and yield of the same furnace fed by blast, heated at 300° Fahr., and likewise consuming coke.

3. The consumption and yield which took place in the month of July last, with hot air and raw coal.

These results are extracted from the cast iron book of the establishment.

Consumption and yield of No. 3, blast furnace in 1828, with cold air and coke.

	Coke.	Calcined ore	Limestone.	Pig Iron. No. 1.	Pig Iron. No. 2.	Pig Iron. No. 3.	Pig Iron. Total.
	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.
From January 6, to February 3	550 2 0	276 8 0	105 3 0	95 4	39 1	20 3	154 8
From February 3, to March 2	545 1 0	274 5 0	101 0 1	100 1	34 2	18 2	152 5
From March 2 to 30 …………	575 0 1	295 6 1	103 0 0	106 6	44 3	15 14	166 3
	1670 3 1	845 19 1	314 3 1	301 11	117 6	53 19	472 16
Loss in coal by coking, 55 per cent.	2041 6 1	563 18 1	Loss of mine 40 ℔ cent.				
Coal ………………………	3711 10 0	1409 18 0	Uncalcined ore.		Pressure of blast 3¼ lbs.		

Consumption and yield of No. 3, *blast furnace in* 1831, *with air heated to* 300° *Fahr. and with coke.*

	Coke.	Calcined ore	Limestone.	Pig Iron. No. 1.	Pig Iron. No. 2.	Pig Iron. No. 3.	Pig Iron. Total.
	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt	ton. cwt.
From January 2, to 16	189 12 0	120 3 0	52 10 1	57 11	11 0	42 2	110 13
From January 16, to 30.........	204 3 0	130 6 0	64 7 0	46 7	...	27 0	73 7
	393 15 0	250 9 0	116 17 1	103 18	11 0	69 2	184 0
Loss of coal	481 5 0	166 19 1	Loss of mine.				
Coal	875 0 0	417 8 1	Uncalcined ore.		Pressure of blast $3\frac{1}{10}$ lbs.		

Consumption and yield of No. 3, blast furnace, during twelve weeks in 1832 and 1833, with hot air and raw coal.

	Coke.	Calcined ore.	Limestone.	Pig Iron. No. 1.	Pig Iron. No. 2.	Pig Iron. No. 3.	Pig Iron. Total.
	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.	ton. cwt.
From Nov. 4, to Dec. 2, 1832 ...	406 0 0	379 2 0	65 5 0	102 15	62 0	55 10	220 5
From Feb. 24, to March 23, 1833	458 8 0	389 6 1	64 7 1	116 10	31 0	52 10	200 0
From March 24, to April 21, 1833	476 4 0	427 14 1	53 19 1	121 10	36 10	62 0	220 0
	1340 12 0	1196 3 0	183 12 2	340 15	129 10	170 0	640 5
Loss in mine		797 8 0					
Uncalcined ore		1993 11 0		Pressure of the blast, 2¾ lbs.			

The comparison of these Tables shows that for one ton of pig iron produced, No. 3, blast furnace consumed;

In 1828, with cold air and with coke.	In 1831, with air heated to 300° Fahr. and with coke.	In 1833, with air heated to 612° Fahr. and with raw coal.
Coal. ton. cwt.	ton. cwt. ton. cwt.	ton. cwt. ton. cwt.
7,075 of coke, answering to 15,724 of coal ... 7 17 0	Coke answering to coal...... 4 15	Raw coal...... 2 2
For heating apparatus ...	Reckoned at ... 6—5 1 0	Reckoned at... 8—2 10 0
Calcined ore 1 18 0	.... 1 7 0	.... 1 17 0
Answering to, Uncalcined ore 2 19 0½	.... 2 6 0	.... 3 0 0
Limestone 13 0	.... 12 0½	.... 5 0⅔

The consumption of the steam engine must be added.

This furnace produced every four-and-twenty hours,

Pig iron 5 12 0¼	.... 6 13 0	.... 8 4 0¼

Thus the consumption of fuel has diminished in the proportion of 7 tons 17 cwt. to 2 tons 2 cwt. There has also been a great diminution of expense in limestone, of which only 5½ cwt. are now used, instead of 13 cwt. which were used in 1828. This decrease results, as I have already said, from the high temperature which the furnace has acquired since the introduction of hot air. I shall point to you at the end of this Report, the reasons which induce me to conceive that there is an increase of temperature in the furnace, although we have no means of measuring it.

The quantity of blast has been reduced from 3500[12] cubic feet per minute, to 2627 cubic feet; the pressure has been very little altered, it is reduced from 3¼ to 2¾ lbs.

The consumption of coal for the apparatus, varies from 7 to 8 cwt. to the ton of pig iron.

The consumption of the blast engine remains the same; but as it blows an additional furnace, and as the quantity produced has been increased from 5 tons 12 cwt. to 8 tons 4 cwt. it is in fact

12 The blowing engine used at Calder is composed of two cylinders placed one upon the other, and having the same axis, so that the pistons of the two cylinders are upon the same piston rod; the upper cylinder is 50 inches in diameter, the lower cylinder 7 feet; the length of the cylinders is 8 feet, the stroke of the piston only 7; the piston is 9 inches in thickness, and the number of strokes is 16 per minute.

reduced from 1 ton 4 cwt. to 14 cwt. to the ton of pig iron. (Slack alone is used for the purpose.)

The consumption of ore has sustained some remarkable variations, but the furnace cinders never containing more than from .02 to .015 of iron, it depends very much upon whether ball or flat ironstone is used.

At Calder as well as at the Clyde works, the daily produce of pig iron has been very much increased; say from 5 tons 12 cwt. to 8 tons 4 cwt. This circumstance has a considerable effect on the cost of pig iron, as may be seen by the following table.

Cost of the manufacture of a ton of pig iron at the Calder works.

In 1828, with cold air and coke.	ton.	cwt.		£	s.	d.	In 1833, with air heated to 322° cent. and raw coal.	ton.	cwt.		£	s.	d.
1st. Coal													
For fusion, at 4*s.* 6*d.* ℔ ton……	7	17	0½	1	15	5	at 5*s.* ℔ ton. …………………	2	2	0		10	6
For the blowing machine, 1*s.* 8*d.* ℔ ton ………………………	1	4	0		2	0	………………………………		14	0		1	2
2nd. Uncalcined ore, 6*s.* ℔ ton	2	19	0½		17	10	Calcined ore, 12*s.* …………	1	17	0	1	2	2
Expense of calcination 10*d.* ℔ ton						10							
3rd. Limestone, 7*s.* …………		13	0		4	6	………………………………		5	0½		1	10
4th. Labour, 10*s.* ℔ ton………		10	0		10	0	Reduced in proportion to the						
5th. General charges, &c. 6*s.* …		...			6	0	produce …………………		...			14	0
Coal for the apparatus……		...			...		………………………………		8	0		1	0
Total………………………£				3	16	7	Total ……………………£				2	10	8

Monkland Iron Works Apparatus.

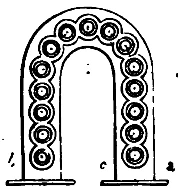
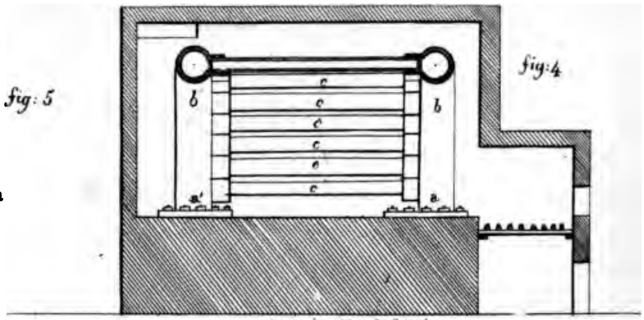


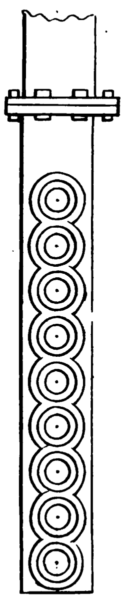
fig: 5

Vertical section
of the large pipe a.b.



Longitudinal Section.

Calder Apparatus.



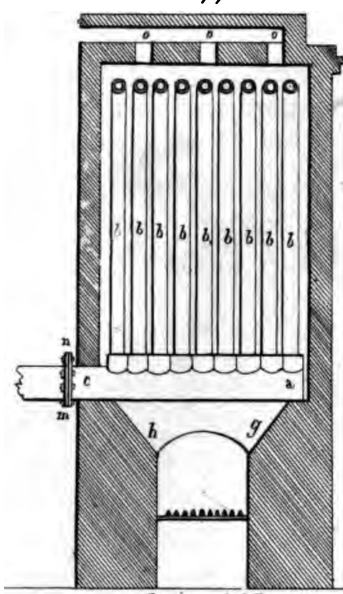


fig: 7.

Section at A B

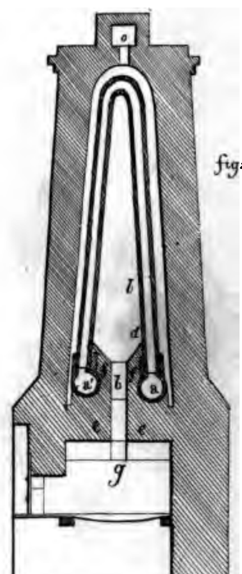
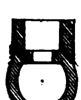


fig: 6

Transverse Section.

fig: 8



Detail of the great pipe
a.c on a double scale.

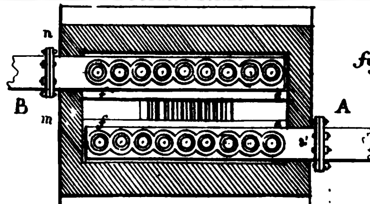
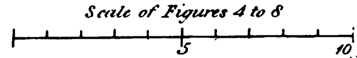


fig: 9

Plan

Scale of Figures 4 to 8



Jan 9. 1836.

MONKLAND IRON WORKS, NEAR AIRDRIE. The apparatus for heating air used at this establishment is very similar to that at Calder; being composed of two large pipes and a number of small ones, which are joined to the large ones. Their relative positions alone are changed. The two large pipes are formed like a horse shoe, and placed vertically; the small pipes are horizontal and 5 feet long. This difference of position, and above all the diminished extent of the small pipes, does not allow so high a temperature to be given to the air by this apparatus as by those at the Calder and Clyde works. At the time I visited the establishment at Monkland, the air was only heated to 450° Fahr., and coke was still used for smelting.

The saving of coal and limestone at these works is nearly the same as at Calder, when the air was only heated in 300° Fahr., and when coke was still used in the furnaces. Indeed before the introduction of the hot air process, from 7 to 8 tons of coals to the ton of pig iron were used at the Monkland works; since that period the quantities of materials used, have been :—

Four tons of coal to the blast furnace.

Six cwt. for the apparatus for heating the air.

Three ton and a half of raw mine.

Half a ton of limestone.

The daily produce of the blast furnace is now 6 tons.

The pressure of the blast is now $2\frac{3}{4}$ lbs. It was 3 lbs.

The pig iron produced in the three iron works of which I have given the details, is chiefly intended for castings. The No. 3, pig iron alone is made into bar iron, and is sold for that purpose to the forges of Newcastle.

Besides the works of which I have given these particulars, there are three others in Scotland in which hot air is used; the results obtained in these establishments are similar to those which I have quoted, and it therefore appears useless to notice them in this Report.

Iron works in the neighbourhood of Newcastle-upon-Tyne.

In the coal basin of Northumberland (the richest and most extensive in Great Britain, which furnishes almost the whole of the coal used in London and on the banks of the Thames), there are only two iron works, one called Birtly Iron works, six miles from Newcastle, on the London road; the other Tyne iron works on the banks of the river, three miles from the town. The small quantity of iron manufactured in a

country full of rail roads, and in which the consumption of cast iron is so great, is owing to the poverty of the coal field in iron ore. So great is the scarcity, that it is impossible, notwithstanding the most minute search, to carry on these two establishments with mine from the coal field exclusively. But their position enables them to draw their supplies from Lancashire and Cornwall at a cheaper rate, than that at which our (French) iron works are furnished.

Hot air has been used for the last twelvemonth in these two establishments. The Birtly iron works have only been constructed three years; they consist of two blast furnaces 45 feet high, four air furnaces, and several cupolas. All the pig iron made at this establishment is used for castings.

The hot air apparatus made use of in these works, does not produce results sufficiently successful to call for a plan of it; it consists of a pipe returned five times upon itself at right angles, and disposed in such a manner that the section presents five circles, of which four have for their centres the angles of a rectangular parallelogram, and the fifth has the point where its two diagonals intersect. These pipes are placed horizontally, and are connected with one another by screws and keys. The interior

diameter of these pipes is 14 inches; they are 1½ thick; the length of the heated part is 50 feet. The pipes are placed horizontally in a rectangular furnace rather shorter than they, so that the angles are not exposed to the fire.

The heat of the air on issuing from the apparatus does not exceed 400° Fahr. It is constantly ascertained by means of a mercurial thermometer. The consumption of this apparatus is 6 cwt. of large coal to the ton of pig iron produced.

The pressure of the air is 1½ lb., the same as before the introduction of hot air; the quantity of blast is now slightly reduced, more blast being given to the cupolas.

The charges of this furnace are composed of,

700 lbs. of coke (the coal gives 45 per cent. of coke.)

650 lbs. of calcined ore (composed of an equal mixture of the mine of the coal field and of the red ore of Lancashire.)

400 lbs. of limestone.

According to the charge plate, No. 1 furnace went,—

$$\left.\begin{array}{l}\text{July } 10 \ldots 40 \\ \phantom{\text{July }} 11 \ldots 42 \\ \phantom{\text{July }} 12 \ldots 38\end{array}\right\} \text{40 charges on an average.}$$

This same furnace produced, in these three

days, 23 tons 11 cwt. or 7 tons 17 cwt. daily. Calculating from these data, we find that a ton of pig iron requires at Birtly,

	ton.	cwt.
Coal for fusion	4	0
Large coal for the apparatus ..		6
Calcined ore	1	13
Limestone	1	0

The quantity of flux used appears very considerable, in consequence of its being charged with a great deal of water. It is the marly chalk which is found on the banks of the Thames, and is brought as ballast by the coal vessels.

The mixture of calcined ore contains 60 per cent. of iron.

In order to appreciate the saving made since the introduction of hot air into the Birtly works, it is necessary to know what was formerly the expense of making a ton of pig iron there. I could not obtain these particulars, but Mr. J. Hunt, manager of the establishment, assured me that they consumed 7 tons of coal.

A comparison of these results, with those obtained in Scotland, shows that the consumption at Birtly nearly corresponds with that at Calder in 1831, when coke was still burned there, and the air was not raised above 300° Fahr. At Newcastle the value of the coal is an obstacle to

its being used raw; as in this state it is necessary to use it in large pieces, which cost 6*s.* per ton, whereas the small coal is only 2*s.* However it would be useful to give the air a higher temperature.

Tyne Iron Works.—The proportionate consumption in these works is nearly the same as at Birtly; but one important distinction exists between these two establishments, which is that at Tyne Iron Works, a great part of the pigs is converted into bar iron. This iron is of a superior quality, and is almost exclusively applied to the manufacture of boiler plates. As these varieties of pig iron are made in the same furnaces, and with the same materials, they depend alone upon the different proportions of minerals and coke.

In the establishment which I am now treating of, the cupolas (or Wilkinson furnaces) are also blown with hot air. Their consumption is 225 lbs. of coke to the ton of cast iron. As these furnaces have only been constructed since the adoption of hot air, we have no comparative results.

The Neighbourhood of Manchester and Liverpool.

The Rant Iron Works, near Wrexham, in Flintshire, and those of Apedale, Lane End, and Silverdale, near Newcastle-under-Line, Stafford-

shire, have adopted the hot air system. The apparatus used in these several establishments are very similar to that at Calder. The results also obtained since the introduction of hot air, are almost the same as those at the Calder works, the temperature being raised from 600° to 612° Fahr.

The consumption of coal, formerly 6 tons, is now reduced to $3\frac{1}{4}$ tons[13] to the ton of pig. As the coal is sulphureous, coke is still used; the apparatus consumes 7 cwt. to the ton of pig iron.

A great diminution has also taken place with regard to limestone; 4 cwt. to the ton of pigs is now the proportion required.

When I visited Apedale last July, only one furnace was working. It had been working for five years, and the hot air had been applied to it eighteen months.

Since that period the produce of this furnace has been increased from 6 to 7 tons per diem. The pig iron it produces is almost entirely No. 1, whilst, previously, it yielded in nearly equal pro-

[13] The proportion of the charges at Apedale is,—

300 lbs. of calcined ore.

500 lbs. of coke. (The coal produces 50 per cent. of coke.)

60 lbs. of limestone. (Transition limestone.)

The furnace drives 36 to 40 charges in twenty-four hours.

portions, No. 2. and 3.; this last quality was sold to be made into bar iron.

A work near Newcastle belonging to Mr. Firmstone, has abandoned the hot air process. I should much like to know the cause of this; but I heard of the circumstance too late to be able to visit the work.

Neighbourhood of Derby.

The coal basin of Derby, which is a continuation of that of Sheffield, contains several large iron works; three of them, Butterley iron works, Codnor Park, and Alpdon, have adopted the hot air system. I visited the two former, which belong to Mr. Jessop, one of the most intelligent iron masters in England. The apparatus made use of in each of these establishments differ from those which I have described, and also differ essentially from one another. These circumstances have induced me to describe them, though their results are less advantageous than those obtained by the apparatus of small pipes at Calder.

Butterley Iron Works.—This work consists of three blast furnaces. The pigs produced are applied to castings, whether of the firts or second fusion. One furnace alone was working when I was in Derbyshire.

tus.

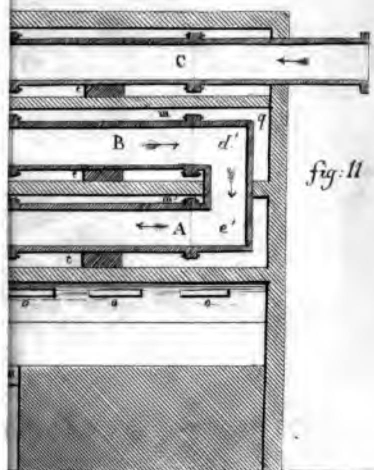


fig: 11

e.

ratus.

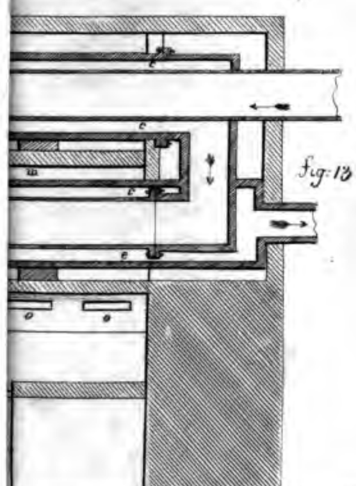


fig: 13

Jan? 1836. 3

The air for the blast was heated by means of an apparatus placed at each tuyere. These apparatus (fig. 11 and 12.) are composed of three large pipes, A B C, of 27 inches interior diameter, placed horizontally above one another, and each separated by flat arches, *m n m' n'*. These pipes are connected two and two by elbow pipes, *d e d' e'*, and exhibit straight folds like the tube of a trombone. The air, in leaving the blowing engine, enters the apparatus by the pipe *c*, and leaves it again at *g*, after having run the whole length successively of the three pipes. The joints are placed outside the furnace itself, but to prevent the air from cooling as it passes these angles, they are covered with a coating of bricks.

The elbow pipes, which establish the communication between the horizontal pipes, are flat. They have flanches to them, and are joined by pins and screws. The pipes are an inch and a half in thickness. They rest upon pillars of bricks *tt*, placed at certain distances upon the flat arches *m n m' n'*. This arrangement allows the flames to surround the pipes on all sides. The first pipe A is not directly exposed to the action of the fire; it is separated from the grate by an arch which runs the whole length of the apparatus, and which allows the flame to escape through the flues *o o*. The partitions *m n*, have

openings p and q placed at the extremity opposite the furnace, in such a manner as to force the flame to pass through the whole length of the furnace, before it escapes from one story to another.

All the arches are of fire brick, and are one brick thick.

The consumption of this apparatus is 15 cwt. of coal to the ton of pigs. The air is heated to the temperature of 360° Fahr. Notwithstanding this low temperature, the consumption of coal has diminished in a large proportion, as appears by the following calculations.

Consumption and produce of No. 2. furnace, worked with cold blast, in the first week of July, 1830,—

159 ton.	5 cwt.	of	coke, equal to
218 ,,	10	,,	coal
109 ,,	17	,,	mine
35 ,,		,,	limestone

Produce, 83 ton of pig iron.

Consumption and produce of No. 2. furnace, worked with heated air, July 17, 1833,—

41 charges were cast into the furnace, each consisting of—

Raw coal	9 cwt.
Calcined ore	9 ,,
Limestone	3 ,,

The average of the first fortnight in July, was 40 charges per diem, and 7 tons of pigs produced.

On comparing the consumption at these two periods, we find that 1 ton of pig iron required—

In 1830 With cold blast and coke.			In 1833 With hot air and coal.		
	ton.	cwt.	ton.	cwt.	
Coal	5	16...	2	18	including the consumption of the apparatus
Mine	3	0...	2	11	
Limestone	1	0...	About 1	0	

To know the whole expense of fuel, that of the blowing engine must be added, of which I have no exact statement; but this must have diminished in proportion to the augmentation of the produce of the furnace.

By the adoption of the hot air process at Butterley, a saving of one half has therefore been effected in the article of fuel. As for the consumption of limestone, it has remained the same; this large proportion of fluxing matter is rendered necessary by the sulphureous nature of the coal.

The quantity of blast which formerly was 2500,[14] is now only 2160 cubic feet per minute.

[14] The blowing engine which formerly supplied two blast furnaces, now blows three. It is true that in order to obtain blast

The pressure of the air is $2\frac{1}{2}$ lbs., and has not varied. The opening of the muzzles has been enlarged from $2\frac{1}{2}$ to 3 inches.

The iron produced is dark pig iron for castings.

Codnor Park Iron Works.—These works consist of three blast furnaces, three fineries, and the requisite number of puddling furnaces for converting the pigs into bar iron. Hot air and raw coals have been used in these works for a twelvemonth. The substitution of hot air has produced at Codnor Park a saving of fuel equal to that at Butterley. 2 tons 9 cwts. of coal are now sufficient to make a ton of pig iron, which formerly required 5 tons. It should be remarked, that the expenditure in coal has always been rather less considerable at Codnor Park than at Butterley, owing to the different quality of the pigs obtained at these two works. The difference of consumption would be much more apparent, if the same sort of coals were used in them both, but that of Codnor Park is soft coal, whilst

enough for three furnaces, it was necessary to enlarge the diameter of the cylinder in a trifling degree. When the machine blew two furnaces only, the dimensions were—70 inches diameter; length of the stroke, 8 feet; number of strokes per minute, 13. The cylinder is now 80 inches diameter; but the length and number of the strokes remain as before.

that used at Butterley[15] is cherry coal, which resists the action of the blast much better.

The apparatus used at Codnor Park for heating the air is composed of two pipes A B (fig. 13. and 14.) placed one upon the other, and into which the small pipes *a* and *b* are inserted, having the same axes with the pipes A B. These different pipes are joined by elbow pipes, in such a manner, that the air, in leaving the blowing engine, enters the inner pipe *b*, spreads itself through the circular space *c d*, comprised between the pipes B and *b*, then passes through the other internal pipe *a*, and is thrown into the furnace by traversing the second annular surface A.

This arrangement of double pipes, one within the other, was adopted to remedy a serious inconvenience which was felt at Butterley and is incident to pipes of a large diameter; in which the air becomes unequally heated, and causes a current

15 With cold air.

At Butterley,	At Codnor,
5 tons 16 cwts.	5 tons.

With hot air.

	At Butterley ton. cwt.	At Codnor ton. cwt.
	2 12	2 9
For the apparatus...	6	6
Total...	2 18	2 15

of cold air along the centre, rendering it impossible to elevate the temperature to a high degree.

The pipes A B, are of cast iron. They have 30 inches exterior and 27 interior diameter. The little pipes *a b*, are of sheet iron, six tenths of an inch thick, and their interior diameter is 18 inches.

The arrangement of the furnace is exactly the same as at Butterley, of which the fig. 13. and 14. give an exact representation.

By means of this apparatus the air is heated to 400° Fahr. The consumption is 6 cwt. of coal to the ton of pigs.

I have already mentioned that all the pigs made at Codnor Park are converted into malleable iron. This iron is used, in Mr. Jessop's own factory, in the construction of different machines, and it is equally adapted to the manufacture of boiler plates, which require very good iron.

The Neighbourhood of Birmingham.

The introduction of hot air has scarcely commenced in the numerous Staffordshire iron works. The prevalent opinion that pigs obtained by this process make bar iron of inferior quality, retarded the trial until the beginning of this year: one work alone, near Wednesbury, belonging to

Messrs. Lloyd, Forster, and Co., is carried on with hot air;[16] the success it has met with at this establishment, has drawn attention to it, and at the period of my visit to Birmingham, three other works were taking measures for making similar trials.

The apparatus used in the establishment of Mr. Forster is placed above the tunnel head of the furnace, and is, I think, the only one of that nature in England; it is composed of a solid annular pyramid (fig. 15. and 16.) A B C D, and of a series of small pipes *t*, which extend into the furnace.

The interior surface *a b c d*, of the solid ring, composed of a long cylinder of cast iron, 4 feet in diameter and 12 feet high, is substituted for the chimney which usually surmounts the tunnel head. The exterior surface of this same solid body presents the appearance of a pyramid of eight sides. It is composed of plates of sheet iron, riveted together like a steam boiler; its diameter at the middle of its height is 6 feet. The result of which is that the average of the circular space is 2 feet in breadth. To protect the exterior surface of this apparatus from the contact of the air, it is covered with a casing of

16 [Since this work was written, several other works in Staffordshire have adopted the use of hot air.—*Trans. Note.*]

bricks. The blast issuing from the blowing engine is carried to the top of the furnace, and expands itself into a circular pipe, *e e e*, placed at the top of the tunnel head. It subsequently divides itself into eight vertical pipes, *f g*, which are raised opposite to the faces of the pyramid, and which are adapted upon the circular pipe; lastly, each of the vertical pipes communicates with six small pipes, *t*, which traverse the annular surface horizontally, and are prolonged to the interior of the tunnel head. This part of the pipes, *t*, enters into the pipes *t'*, being closed at their extremity in such a manner, that the air by its movements is forced to spread itself over the circular surface. These different pipes are of cast iron; the junction of the pipes *t*, with the pipes of distribution, *f g*, takes place by means of leather bags, *t''*.

The air being heated in the pipes *t'*, under the circular ring A B C D, *a b c d* descends again towards the tuyere by means of a conducting pipe *v*, which, to prevent the air from cooling during the passage, is placed in the chimney of the steam engine, at a distance of 12 or 15 feet, a species of bridge made of bricks, *h i*, connects this chimney with the top of the furnace.

Notwithstanding these precautions, the air in this apparatus does not exceed a temperature of

360° Fahr. In order to give it a more elevated temperature, it is necessary to re-heat it in a stove at a few feet from the tuyere of the furnace.

The consumption of this stove is about 4 cwt. to the ton of pigs.

This apparatus was very expensive, and requires very frequent repairs. The trifling saving of coal which it produces (about 3 cwt. to the ton[17] of pigs) is more than counteracted by the expense of building and keeping it up; and, above all, by the numerous stoppages which result from the almost daily repairs.

In Messrs. Forster's establishment, the introduction of hot air has produced savings similar to those which I have already noticed, as having taken place in all the works where this process has been actually adopted; 1 ton of pig iron required in 1831, 3 tons of coke, or 5 tons 9 cwt. of coal. The same quantity of pig iron now only requires 2 tons 14 cwt. of coal, as may be seen in the following statement.

On July 20, forty charges were thrown into the furnace, each consisting of—

10 cwt. raw coal
9 ,, calcined ore
6 ,, limestone.

[17] The average consumption of the apparatus for heating the air amounts to 7 cwt. to the ton of pigs produced.

Eight tons of pig iron were produced; so that each ton consumed—

	ton.	cwt.	ton.	cwt.
Coal for fusion	2	10		
„ for the heating apparatus		4—	2	14
Calcined ore			2	5
Limestone			1	10

The consumption of limestone is considerable, which is owing to the sulphureous nature of the mine; the cinders which proceed from this furnace are crystalline, transparent, and emit a strong smell of sulphur.

Previous to the introduction of hot air, the produce of this furnace was only 6 tons per diem. Thus, besides the saving in coal, a diminution has been obtained in general charges and in labour. The quantity of blast has not sustained any alteration; the opening of the muzzles have been, however, enlarged from 2¾ inches to 3½ inches.

A portion of the pigs produced in Messrs. Forster's establishment is designed for casting, the other is transformed into finer's metal. The same casting gives both species of pigs; that which first issues from the hearth, and which runs to the bottom, is No. 1, and the upper of the hearth gives No. 2. These two sorts of pig iron are distinguished by the manner in which

they run, and by the streaks which appear on their surface when they cool.

Iron Works in Wales.

In Wales there are but two works carried on with hot air, that of Varteg and that of Blaenavon, ten miles from Abergavenny. None of the works at Merthyr Tidvil use this process, although attempts to introduce it have been made at several of them, particularly at Dowlais and Penydarran. The system being relinquished in so extensive an iron country, and where the proprietors are constantly employed in making improvements, has thrown great doubts upon the reality of the advantages which result from it.[18] Some of the least sceptical have thought, that although the process might be advantageous in Scotland, where the pigs were used for casting, it would not answer where the iron was intended to be converted into bar or malleable iron. The examples afforded by the works of Newcastle, Codnor Park, and Wednesbury, in which bar iron of a very superior quality is manufactured, prove that this opinion is not well founded. The real cause of the process being abandoned in

18 [This statement is incorrect. Hot air had not been used at either Dowlais or Penydarran at the time this treatise was written.—*Trans. Note.*]

Wales probably was partly the bad arrangements of the apparatus, but more particularly the very small saving which would result from using raw coal, compared with the expense of the patent. In order that these reasons may be fully appreciated, it is necessary to enter into some detail upon the expense of manufacturing pig iron in this country.

From the few particulars which I was able to collect at Dowlais and Penydarran, it appears that the apparatus was of a very bad construction, and did not permit the air to be carried above 300° Fahr.

[19]Notwithstanding the temperature of the air being so low, the substitution of coal for coke was tried with success. An accident happened to the apparatus, which prevented the hot air from being used for some days; and during that period it was discovered that raw coal might be used without inconvenience, even with cold blast. So great was the saving which resulted from this substitution, that the apparatus, which was nearly worn out, was not replaced: since that time some of the Welsh iron works have used coal; some of them use a mixture of coal

[19] [This is altogether incorrect. The raw coal was first introduced by Mr. Guest, at Dowlais, without hot air, and he was followed by the Penydarran Company.—*Trans. Note.*]

and coke. The following table shews the quantity of coal now required for making a ton of pigs.

At Penydarran.				Dowlais.		Cyfarthfa.			Plymouth.		
	ton.	cwt.		ton.	cwt.	ton.	cwt.		ton.	cwt.	
Coal	2	9	0	2	14	2	13	0½	2	13	0
Calcined ore	2	4	0	2	9	2	6	0½	1	16	0
Cinders......		2	0½	...		...	...		...	...	
Limestone...		19	0½		13		16	0	...	...	

To this must be added the quantity of coal used for the blast engines, which, supposing the same quantity to be used in all the works, varies from 5 to 6 cwt.

The quantity of coal used at these works is therefore, on an average, 2 ton. 10 cwt. to the ton of pig iron. The saving which the use of hot air might produce in the consumption of coal, would be, I think, at the most one third of the present expenditure, 17 cwt., from which must be deducted the consumption of the heating apparatus which may be reckoned at about 6 cwt. The saving would therefore only amount to 11 cwt.; which at 3*s.* 7*d.* per ton, (the cost price of coal in Wales,) would be equal to a saving of 1*s.* 8*d.* per ton; and as the patent right is charged at 1*s.* per ton, the actual saving would be only 8*d.* This trifling saving would be very

little felt in a country where the cheapness of materials admits of cast iron being made at a much lower price than in any other part of England.

I think, therefore, that the non-adoption of this process in Wales is no evidence that it would not effect a saving of fuel; on the contrary, every thing leads me to think that a saving would take place, as in the other works where this method is in operation; but it is evident that the expense of coal is so small in Wales, that it would not be so considerable as in the Scotch works.

The Varteg iron works, which have been mentioned in the commencement of this section, confirm this opinion; in that establishment, the apparatus for heating air has but a small range of pipes, so that the air cannot attain a temperature higher than 400° Fahr.; the coal, which is very bituminous, and which loses 55 per cent. in coking, is not capable of being used in its natural state in the furnace. Owing to this circumstance the saving at these works is not so great as in those of Scotland; but it is equal to the saving obtained in that country, when the apparatus was not carried to a high state of perfection, and when coke was still used: however, the diminution of the cost price of iron is considerable; in-

deed, before the introduction of hot air 1 ton of pigs consumed 2 ton. of coke,[20] answering to 4 ton. 3 cwt. of coal; the consumption of coke is still about 2 ton., but the coal is not obliged to be so completely carbonized, and then 2 ton. ot coke represents only 3 ton. of coal. The produce is increased from 6 to 8 ton. of pigs in the four and twenty hours.

The Use of Hot Air in the Cupolas (of Founderies).

There are several cupolas, in which combustion is kept up by a current of hot air. From the slight attention which is bestowed in England on the consumption of coal, which is every where to be found in great profusion, trouble is seldom taken to weigh the coke thrown into the cupolas. This circumstance prevented me from ascertaining the advantages which result from this new process; I think, however, it may be useful to make known the few particulars which I collected on the subject. I shall also give a description of the two apparatus placed at the tops of cupolas.

At the Tyne iron works, which I have already mentioned in speaking of the works near New-

[20] These figures were given me by Mr. Kenrick, one of the proprietors of the Varteg works. I had no means of verifying them, as I only spent a few hours in that establishment.

castle, are two cupolas worked by hot air. They are supplied by the same apparatus as the blast furnaces. These cupolas are circular. They are $5\frac{1}{2}$ feet high, 30 inch. interior diameter. Within they are constructed of fire bricks. They are formed on the outside by a cast iron cylinder. They receive the blast by two tuyere pipes, placed one above the other, and having each a diameter of $2\frac{3}{4}$ inches.

According to the accounts which one of the proprietors had the kindness to give me, the consumption of these cupolas is 280 lbs. of coke to the ton of cast iron. One ton of pigs is on an average melted every hour. These cupolas have only been constructed since the adoption of the hot air process.

At Wednesbury, in Messrs. Lloyd, Forsters, & Co.'s works, the cupolas are rectangular; they are about 7 feet high, and their interior space is 36 inches by 30. The blast is conveyed by two tuyeres, 3 inches in diameter. One ton of pig iron is melted every hour, and each operation lasts 20 minutes. The consumption of coke is 260 lbs. to the ton of pig iron; before the introduction of hot air 400 lbs. of coke were requisite for the same quantity of pig iron. The greatest influence the hot air possesses in the cupolas is upon the length of the operation; a casting

which now occupies 20 minutes, required 40 previous to the adoption of this process.

The result, therefore, at Wednesbury is, that 1 cwt. of pig iron, which with cold blast required 20 lbs. of coke, consumes only 13 since the cupolas have been blown by hot air.

Messrs. Coste and Perdonnet (Annales des Mines, 2nd series, vol. vi. p. 85.) observe that the quantity of coal consumed in the cupolas of Birmingham, Manchester, and Newcastle, is upon an average 25 per cent.; if these figures are compared with the particulars which I have given, it will appear that the adoption of hot air has produced a saving of one half in the consumption of coal, and in the other expenses incurred by melting pig iron the second time.

In some of the works where the air intended to blow the cupolas is not heated by the apparatus which feeds the blast furnaces, it is heated by the flame which escapes from the tops of the cupolas: I subjoin a succinct description of two of these apparatus which are placed at the tops of the cupolas; they were constructed by Messrs. Jeffries and Patton, London.

The apparatus represented (fig. 19. and 20.) consists of a series of pipes *a*, *a*', *a*'', horizontally disposed above the top of the charging plate, and communicating by means of elbow pipes, in the

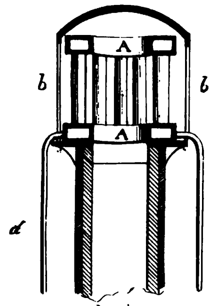
two boxes *b* and *b'* placed upon the vertical surface of the cupola: on issuing from the blowing engine, the air passes by the pipe *c*, and the compartment *d* of the box *b*, and goes into the pipe *c'* and the compartment *d'* of the box *b'*; following the direction of the arrows, it subsequently reaches *f*, where it divides in order to distribute itself between the two tuyeres; all the parts of this apparatus are of cast iron.

The second apparatus (fig. 17. and 18.) is composed of a series of vertical pipes *a*, disposed circularly upon the jambs of the tunnel head; these pipes, which are of three inches diameter, communicate at their extremities in two rings *A* and *A'* placed, the one immediately upon the top of the cupola, and the other on the upper part of the pipes *a*. A large cylinder of sheet iron *b* surrounds the pipes on the outside, and forces the flame to circulate around them.

The blast, on issuing from the blowing engine, reaches the upper ring *A'* by means of the pipe *c* (fig. 18.); it there divides itself among the vertical pipes *a*, *a'*, and unites again in the lower ring *A*: finally it is sent to the tuyeres by means of the two vertical pipes *d*, *d'*.

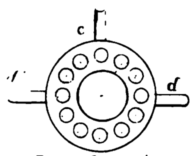
At the upper part of the top of the cupola, and above the lower ring *A*, an opening P is contrived for charging the cupola.

Apparatus adapted to the top of a Cupola.



Section.

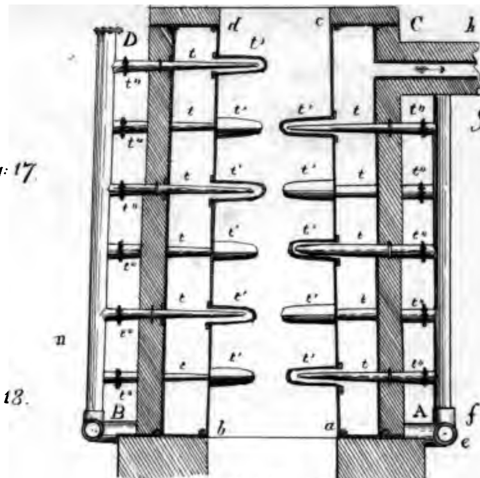
fig: 17



Plan of the ring.

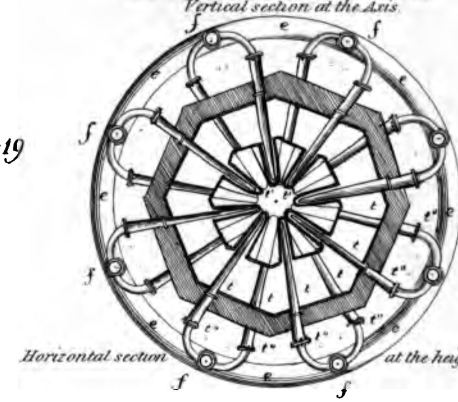
fig: 18.

Apparatus placed at the tunnel head of the Furnace of Wednesbury.



Vertical section at the Axis

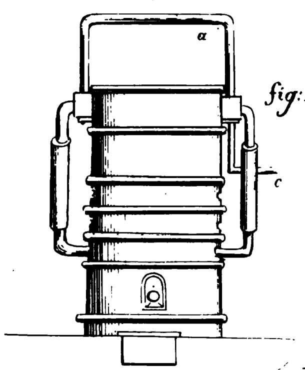
fig: 1



Horizontal section at the height of the wall.

fig: 16.

Apparatus placed upon



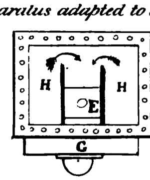
Elevation.

fig: 19

Plan.

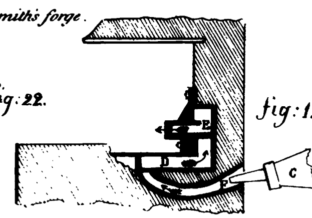
fig: 20.

Apparatus adapted to a Smith's forge.



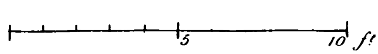
Plan.

fig: 22.



Section.

fig: 12.



Oe. Jan. 1836.

I have not seen this apparatus at work; it appears to me superior to that which I described first; in it the air must acquire a higher temperature, and meet with less resistance to its motion.

Use of Hot Air in Refineries and Smiths' Forges.

Hot air has been tried in the operation of refining metal, and in fires for working iron.

I have not visited the work where the attempt was made to blow the fineries with hot air; but I know that at the Janon forges, near St. Etienne, the results obtained from this process were not favourable to the application of hot air. This was also the case at a work in the neighbourhood of Birmingham: the failure in the use of hot air in refineries, does not invalidate the advantages which it produces in the management of blast furnaces, which are confirmed by numerous examples. The different results between the use of hot air in the furnaces and in the refineries, is partly accounted for by the different purposes to which blast is employed, in the operations of fusing or refining the minerals.

I mentioned at the commencement of this report, that the first trial of hot air was made by Mr. Neilson, in a smith's fire connected with the

gas works at Glasgow. The air is heated by the hearth of the forge, by means of a double box of cast iron, (fig. 21.) which forms the seat of the forge itself. The air passing through the pipe F enters the bottom of the box D, and re-issues by the tuyere E, after traversing the compartments H and H'.

Mr. Neilson was kind enough to have several bars of iron forged in my presence, in order that I might judge of the effect which the use of hot air produced. It is difficult for me to form an opinion of the advantages which result from this process, as I have not seen any comparative trials made; and I own that it hardly appears to me, that the slight temperature which the air may acquire in the apparatus adapted to the forge, can have any very great effect on the operation.

The hearth was completely cleared, in order that I might see the exterior arrangement of the apparatus, and judge of the time necessary for welding; the fire was then relighted, and in the space of four minutes from the moment that the first lighted coal was placed in the forge, a bar of iron of an inch square was brought to a white heat. Being taken from the fire, this bar emitted very brilliant sparks, and the small quantity of cinders which covered it ran in very thin and liquid drops. The bar having been plunged into

the water, remained after a minute's immersion of a dull red colour, and hot enough for forging.

I could not ascertain the quantity of coal consumed; it varies considerably according to the dimensions of the pieces forged: Mr. Neilson however assured me that the consumption of coal had been reduced one third since hot air had been used.

In several smith's forges, this new process has been adopted; in order to obtain the right of using it, it is only necessary to buy the apparatus of Messrs. Jeffries and Patton of London, whom I have already mentioned as sellers of the apparatus to be placed at the top of cupolas.

Trials of Hot Air in France.

Several of the French iron masters have for some months attempted to introduce the hot air process into their works; M. Boigues, who has so powerfully contributed to the progress of the manufacture of iron, by the construction of a beautiful forge on the English system at Fourchambault (in Nièvre) also made the first attempt to introduce hot air. Several other works, as those of Vienne (in Isere), of La Voulte (in Ardèche), of Rieupéroux (near Grenoble), have also adopted this process.

The apparatus constructed by M. Boigues

exhibits a long range of pipes, like that at Clyde. The furnace of Torteron (in Cher), to which he has applied this process, is fed by a mixture of charcoal and coke. The application of hot air in this furnace has not produced (as was expected) a saving of fuel; but the nature of the pig iron is completely changed. From white it has become grey, and this furnace now produces pig iron fit for the most delicate castings, and quite equal to the English pig iron. When this iron is run into pigs the grain is large, of a scaly composition, and very brilliant. The grain of these pigs becomes much closer when it is run into thinner pieces, or moulded at the second fusion; in this case it is extremely soft under the shears.

The Torteron furnace has been working eight and twenty months; the progress is very regular, and the charges succeed one another at nearly equal intervals; on an average, from 42 to 48 charges are made in the twenty-four hours; two sorts of ore are used in it; one called cold mine is the true iron ore of Berry; it is composed of small round grains of a brown colour, or with a slight ochrous tinge. The second sort, called hot mine, is very argillaceous; it is composed of grains scattered among fine and tenacious clay.

In this furnace is used a mixture of charcoal (principally of oak) and coke, bought in the mines of St. Etienne.

I have not the data necessary for determining with accuracy the alteration in the consumption of fuel, produced by the use of hot air in the blast furnace at Torteron; but the results obtained in two furnaces, situated near each other (Torteron and La Guerche in Cher), belonging to the same company, and carried on under nearly similar circumstances, are exhibited in the following tables, for which I am indebted to M. Boigues, who had the kindness to lend me the returns of the establishment.

Consumption and produce of the furnace at La Guerche, blown by cold air.

Weeks.	Charcoal.	Coke.	Mine.	Limestone.	Pigs produced.
	k.	k.	k.	k.	k.
From Nov. 24 to 30, 1833	33320	16800	101500	22400	41524
From Dec. 1 to 7 ,,	34510	17400	99000	22400	40460
From Dec. 8 to 14 ,,	33320	16800	93000	22400	38430
	101150	51000	293500	67200	120414

Coal for the steam engine, from Nov. 24 to Dec. 14.....335 hect., 95.

Consumption and produce of the furnace at Torteron, blown by hot air.

Weeks.	Charcoal.	Coke.	Mine.	Limestone.	Pigs produced.
	k.	k.	k.	k.	k.
From Nov. 24 to 30, 1833	38528	20640	129000	44720	46969
From Dec. 1 to 7 „	34384	18420	115125	39910	40607
From Dec. 8 to 14 „	35504	19020	122675	39625	43307
	108416	58080	366800	124255	130883

Coal for the steam engine, from Nov. 24 to Dec. 24......364 hect., 69.
„ for the apparatus for heating the air ....543 „ 16.

From these tables it appears that the consumption for one ton of pig iron, or 1000 kilog., is,

	La Guerche.	Torteron.
Charcoal	833 kil.	828 kil.[21]
Coke	413 ,,	443 ,,
Mine	2437 ,,	2802 ,,
Limestone	558 ,,	949 ,,
Coal for the steam engine	2,79 hect.	2,71 hect.
,, heating apparatus	,,	415

The comparison of these figures is not favourable to the use of hot air; but the yield of these furnaces cannot be exactly compared, on account of the difference that exists between the richness of the materials that are used; the mine melted in the furnace at La Guerche yields 41 per cent., whilst that melted at Torteron yields but 35. The quantity of limestone added to the mine at Torteron, is nearly double what is used at La Guerche; notwithstanding these two unfavourable circumstances, the daily produce of the Torteron furnace surpasses that at La Guerche. Thus, if the proportion between the

21 The steam engine which blows the furnace at Torteron, is sixteen horse power. The consumption of coal is increased considerably, since this furnace has been blown by hot air; this circumstance proves, what I have already mentioned, that greater power is necessary to throw the same quantity of air into a furnace when it is heated than when cold.

quantity of materials and the fuel were compared, instead of the quantity of fuel consumed and the pigs produced, the Torteron furnace would appear to be more economically carried on than that at La Guerche. In fact, at La Guerche, 1000 kilog. of mixed mine and limestone require 419 kilog. of fuel, whilst at Torteron for 1000 kilog. of the same mixture only 339 kilog. of coal is consumed.

Thus the use of hot air is productive of a considerable saving at Torteron; and has also an advantage, not less important, in its influence upon the quality of the pig iron, which has now become fit for foundery purposes; this circumstance has given it a value, which exceeds by nearly one fourth the price of pig iron produced by means of cold blast.

Besides the blast furnace which I have noticed, there is a cupola at Torteron, blown by hot air.[23] The apparatus made use of for this purpose (fig. 19. and 20.) was bought of Messrs. Jeffries, of London.

I cannot point out the advantages which result from the use of hot air in the cupola, as I am only acquainted with its present consumption.

[23] I am indebted for these particulars to M. Guiot, an out student of the mines, who this year visited the establishment at Fourchambault.

M. Boigues, who was kind enough to communicate these interesting documents to me, considers that this new process has produced only a slight saving of fuel; but the principal advantage is in the acceleration of the process: as the pig iron is not exposed for so long a time to the action of the blast, it does not begin to refine, as often happens. This acceleration of speed also admits of a greater number of castings taking place in a given time.

Consumption of the cupola at Torteron, for six days, blown with hot air.

1833	Consumption.		Produce of castings.		Consumption of pigs and fuel to the 100 kil. of castings.	
	Pig iron.	Coke.	Number of Pieces.	Weight.	Pig iron.	Coke.
	kil.	kil.	kil.	kil.	kil.	kil.
Dec. 8	2700	740	131	2460	108	30
„ 9	3600	1070	246	3345	107	32
„ 10	2550	710	135	2366	108	30
„ 11	2650	740	139	2451	108	30
„ 12	2600	720	126	2380	109	30
„ 13	2400	680	117	2169	110	31
	16500	4660	894	15171	108	30

The use of hot air has been introduced into the furnace at Vienne for the last fifteen months, and has produced a saving of more than one third in fuel. M. Gueymard, in a report to the Director General of the bridges, roads, and mines, (Annales des Mines, IV. 87.) mentions that the consumption of coke, which was 250

kil. 87, to 100 kil. of pig iron produced by cold air, has been reduced to 146, 24.

The quantity of limestone has also undergone a diminution of nearly one half.

The produce, which was formerly 4750 kil. of pig iron in twenty-four hours, has been raised to 5988 kil.

Subsequently to the report which I have quoted, M M. Le Cocq, Defourcy, and Mont-Marin, student engineers of the mines, have, in conformity with the order of the Director General, visited Vienne. They have drawn up a Memoir of that establishment, in which they give very circumstantial details of the consumption of the furnace since the introduction of hot air. The figures they quote entirely confirm the advantages which M. Gueymard predicted from the very first; but, as they give a much longer account, I think it may be useful to make it known.

The following table is an exact transcript from the Memoir I have mentioned.[24]

[24] In the furnace of Vienne, a mixture of mine from La Voulte, Franche Comtè, and Villebois or Buget, is used.

The mine of La Voulte is a mixture of compact oolitic iron and carbonate of iron.

The mine of Franche Comtè comes from Autrey; it is granulated, and gives from 25 to 28 ℔ cent. of iron.

The mine of Villebois, or of Buget, is very poor; it is composed of small oolitic grains, scattered in the limestone. It is used by way of diminishing the proportion of limestone.

Consumption and produce of the blast furnace at Vienne, during the months of September, November, and December, 1832, *and August*, 1833.

	Coke for fusion.	Mixture and quantity of minerals.		Limestone.	Coal for heating apparatus.	Pigs produced.	Number of charges.
	kil.		kil.	kil.	kil.	kil.	kil.
Sept. 1832, with cold air till the 25th, with hot air from the 25th to 30th,	274920	Of La Voulte...145000 Of Comtè ...... 32012 Of the Buget ... 39700	216712	65650	...	90869	1201
Nov. 1832, with hot air,	241696	Of La Voulte...262112 Of the Buget ... 34400	296512	50612	652	143929	1016
Dec. 1832, with hot air,	236104	Of La Voulte...230850 Of the Buget ... 14525	245375	54562	644	122298	1017
Aug. 1833, with hot air,	218391	Of La Voulte...166974 Of the Buget ... 63237	230211	63237	537	108622	1015

From these data a calculation has been made in the following table, of the quantity of coke, mineral, and limestone, consumed, to make 100 kilog. of cast iron, at the different periods named. To this is added the quantity of pig iron produced in the twenty-four hours. To render the comparison with the English Iron works more easy, the coke is transformed into coal; and for this transformation, the hectolitre of coal is considered to weigh 75 kilog., and the coal to render 50 per cent. of coke.

Consumption necessary for obtaining 100 *kilog. of pig iron.*

	Mine.	Flux.	Coal for fusion.	Coal for apparatus.	Total of coal.	Pigs in 24 hours.	No. of charges in 24 hours.	Composition of charges.
	kil.	kil.	kil.	hect.	kil.	kil.		
1828, cold air,	255,00	109,28	275,00	...	550	3500,00	51	Coke 200 Mine 75 Flux 75
Sept. 1832, cold air,	238,45	72,24	302,50	...	905	3028,90	40	Coke 228,90 Mine 180,44 Flux 54,66
Nov. 1832, hot air,	206,01	35,16	167,92	0,453 or. kil. 33,97	369,8	4797,60	33,90	Coke 237,88 Mine 291,84 Flux 49,81
Dec. 1832, hot air,	200,63	44,61	184,87	0,526 or. kil. 39,45	409,4	3945,09	32,80	Coke 232,15 Mine 241,27 Flux 53,64
Aug. 1833, hot air,	211,93	58,21	201,05	0,493 or. kil. 36,47	439,1	3503,92	32,72	Coke 215,16 Mine 226,71 Flux 62,30

It appears from the examination of this table, that the month of November presents the most advantageous results, both with respect to the quantity of pig iron produced, and with respect to the consumption of mine and limestone. It is true that, in this month, the pig iron was almost always mottled, more attention being paid to quantity than to quality.

During the month of August, the quantity of pig iron produced was much less, as well as the saving in the consumption, but it was of a superior quality.

On comparing the produce of 1828 (with cold air) and of the month of November 1832 (with hot air), it appears that the saving of expense, resulting from the use of the latter, was 49 kilog. of mine, 74 kil. 12 of limestone, and 180 kilog. 20 of coal, upon the 100 kilog. of pig iron.

The produce of pig iron has been augmented 1297 kilog. 60, in the twenty-four hours.

Works of La Voulte. — Since last September, one of the three furnaces which compose the works of La Voulte, has been blown with hot air; the apparatus, which was constructed by Mr. Philip Taylor, civil engineer, consists of a horizontal pipe 0^m, 57 exterior diameter, and 48 metres in length, having branches which point to each tuyere; this pipe, which is placed upon

rollers to prevent the inconvenience which might result from dilatation, traverses the heating furnaces erected near the tuyeres. The position of the furnaces, which are built at a distance of only a few feet from an almost perpendicular declivity, opposed a serious obstacle to placing the apparatus. Mr. Taylor surmounted this difficulty by constructing an arch, which is supported both by the hill, and by the back wall of the furnace. The surface exposed to the action of the heat is 177.795 square metres;[24] the quantity of blast thrown into each tuyere is 500 cubic feet per minute.

Previous to the introduction of hot air, seventy two charges were put into the furnace of La Voulte every twenty-four hours. Each charge consisted of—

	kil.			kil.
Mine	230	making in the 24 hours		16560
Coke	200	,,	,,	14400
Flux	60	,,	,,	4320

The mean produce, corresponding with these charges, was 7.000 kil. of pig iron.

As soon as the hot air was applied, the charges

25 Some trials having been made in heaters of a different form, the result was, that in order to raise 100 cubic feet of air ℔ minute, to a temperature of 320, it was necessary to make it traverse a surface of pipes 1^{m}, 66, heated to a reddish brown.

sunk more slowly; on the second day, 20 kilog. of mineral were added to every charge: the furnace worked well, and on the second day 40 kil. more were added to each charge; this second addition of mineral hastened the descent of the charges, which were carried to seventy-six. The cinders were very thin, and bore all the appearance of good work, and the pig iron was crystalized and of a dark grey. During the two following days, 40 kil. more were added to the charge. Mr. Taylor, who directed these trials, finding that the pig iron produced was still too grey for puddling, made another addition of 20 kilog. of mineral.

On the eighth day 76 charges were thrown into the furnace, each consisting of,

Mine..350	making altogether	26600 kil.
Coke..200	....	15200 ,,
Flux.. 60	....	4560 ,,

The produce of pig iron amounted to 11000 kil. of a mottled quality.

Subsequently the number of charges was carried to 84 in the 24 hours, and the produce raised to 14000 kil.

The fuel used for heating the air was 0,25 of raw coal to a ton of pigs.

According to the report of the experiments made by Mr. Taylor at the establishment of La

Voulte, the result was, that owing to the introduction of hot air, the consumption of coke necessary to produce 1000 kil. of pig iron was reduced from 2057 kil. to 1210, including the coal necessary for the heating apparatus, and reckoning this coal to have been transformed into coke.

The La Voulte works exhibit, under the same roof, a furnace blown by hot air, and two furnaces blown by cold air, which are exactly alike in all their other circumstances; the results which have been pointed out may therefore be ascertained at any moment.

At Riouperoux, in the department of Isere, M. Gueymard obtained similar results. The furnace, not long since, consumed 1610 kil. of charcoal to the ton of pig iron. Since it has been blown by hot air (carried to 130 R), it only consumes 1270 kil. of coal, not reckoning the antharcite, or stone coal, which is used to heat the air: (Ann. des Mines, iv. 508.) this result is the more important, as being the first example of hot air applied to a furnace fed by charcoal; it answers satisfactorily the doubts of those persons, who apprehended that the process could not be advantageously employed with this species of fuel.

Trials of Hot Air at Wurtemberg.

The hot air has been recently introduced into the royal foundery of Wasseralfingen, in Wurtemberg, where it has also produced a very considerable saving of fuel. It appears from a notice published by M. Voltz, (Ann. des Mines, iv. 77.) who was appointed by the Director General of the bridges, roads, and mines, to investigate the trials made at Wurtemberg, that the quantity of charcoal necessary for making 100 lbs. of pig iron has been reduced from 185 to 113 lbs., and that the daily produce of pig iron has been carried from 7530 to 10500 lbs.

The apparatus used in the Wasseralfingen foundery to heat the air, is placed above the tunnel head, and does not occasion any expenditure of fuel.

Remarks upon the Nature of different sorts of Coal used in Furnaces heated with raw Coal.

It appears from the foregoing accounts, that certain sorts of coal, viz. those of Wales,[11] are

[11] [This applies only to part of the coal of the Welsh coalfield, as when the coal is very bituminous, it is not used without coking. —*Trans. Note.*]

employed in their natural state for the fusion of minerals in blast furnaces blown by cold air; that several other sorts, the Glasgow coals for instance, are capable of being used in their natural state with hot blast; and lastly, that some sorts appear to require coking, whatever be the process by which the iron is made.

In order to ascertain the causes of such remarkable variations in the properties of the coals, I collected specimens of most of the coals used in the works of which I have spoken in this report. M. Berthier had the kindness to analyse them in the Laboratory of the School of Mines, and I transcribe the results which he communicated to me.

Coal used in their natural state in the Welsh furnaces heated by cold air.

	Dowlais.	Cyfarthfa.	Penydarran.
Coal	0,795	0,784	0,768
Ashes	0,030	0,028	0,032
Volatile Matter ...	0,175	0,188	0,200
	1,000	1,000	1,000

DOWLAIS COAL.—This coal is lamellar; it divides across the beds in thin plates, smooth

and brilliant; it is composed of two distinct parts; the one is brilliant, and separates into small cubic fragments; the other is completely dull, hard, with conchoidal fracture, and is very similar in every respect to cannel coal; these two sorts of coal do not mix, but form, in each vein, small beds, more or less extensive.

The brilliant part very much predominates; the Dowlais coal does not stain the fingers, it swells very little, and is not adhesive; its ashes are quite white.

Cyfarthfa Coal.—This coal is neither schistous nor lamellar; it is composed, like the preceding, of an assemblage of brilliant and of black compact particles, mixed exactly in the same manner as quartz and feldspar are in granite. These two sorts of coal act very differently; the sparkling variety swells, and adheres rather stiffly, whilst the dull part is dry, and does not change its shape by exposure to fire: it is this mixture, probably, which gives to the coal used at Cyfarthfa greater power than is possessed by any other sort, of resisting the action of the blast, and the different movements which occur in a furnace. To this circumstance its friability is also owing; but the bitumen which pervades the sparkling coal causes the different particles of this coal to adhere, and gives it a

great solidity, when it has once been exposed to the fire.[26]

PENYDARRAN COAL.—This is of the same nature as the preceding, except that the mixture of the bright and dull particles is less intimate.

These three sorts of coal proceed from the coal basin of Wales; they are very dry, and to this property they owe the excess of carbon which they contain; they are similar to the Rolduc coal.

[26] The properties of the Cyfarthfa coal suggested the idea of using stone coal, coking it slightly with very rich coal. I was assured that this process, of which I have none of the particulars, had produced very satisfactory results in working blast furnaces.

Coals used in their natural state in furnaces blown by hot air.

	Neighbourhood of Glasgow.			Staffordshire.	Derbyshire.	
	Clyde.	Calder.	Monkland.	Tipton, near Wednesbury.	Butterley.	Codnor Park.
Carbon	0,644	0,510	0,562	0,675	0,57	0,515
Cinders	0,046	0,040	0,014	0,025	0,83	0,030
Volatile Matter: Water	0,005	0,039	0,115			
Volatile Matter: Gas	0,139	0,081	0,094	0,300	0,40	04,55
Volatile Matter: Goudron?	0,166	0,330	0,215			
	1,000	1,000	1,000	1,000	1,00	1,000

The coals in the neighbourhood of Glasgow, used in the Clyde, Calder, and Monkland iron works, are of an uniform nature, and are very similar to each other in their composition, as the foregoing table shows.

This coal is generally dull, rather hard and compact, and does not crumble between the fingers. It presents, in the cross fracture, a series of small lines which give it the appearance of being schistous, although it is not really so. It is very regularly stratified, and the pieces split into flat plates, more or less thick. The surfaces of separation are almost always marked by some black carbonaceous matter, which stains the fingers, and resembles charcoal in its fibrous appearance and dull colour. This coal is frequently intersected by extremely small fibres of carbonate of lime running perpendicularly with the beds: pyrites is also found in it.

Fragments of Glasgow coal, which were analysed, were only slightly softened; they adhered without changing their shape.

The Tipton coal, used in Messrs. Lloyd and Forster's works, near Wednesbury, is schistous: it is composed of small layers several lines in thickness, and which are almost always separated by an extremely thin layer of black carbonaceous matter, resembling charcoal. This friable

substance is so abundant, that it is difficult to find a piece of Tipton coal four inches thick, which does not contain one or two layers of it. This coal, which is sparkling at its fracture, breaks into small regular fragments. It is not very adhesive, and swells but slightly.

The coals near Derby are divided into two principal qualities, called cherry coal and soft coal. The first, which is the hardest, resists the action of the fire best. The Butterley furnaces, which are blown with hot air, consume a great deal of cherry coal. It is a schistous coal, and is marked with dull black lines, which render it very similar to the coal of Scotland.

The soft coal which is principally used for the steam engines and puddling furnaces, is also used for the fusion of iron ore at Codnor Park; it is rather sparkling and schistous, and separates into fragments at the least touch. It contains particles of that black and friable carbonaceous matter, which I have already mentioned more than once.

Notwithstanding the considerable loss which these two sorts of coal sustain by coking, their shape does not change; they do not swell, and adhere very little; the ashes which proceed from them are perfectly white.

Coals which it is necessary to coke, in order that they may be used even in furnaces with hot air.

	Birtly Iron Works, near Newcastle.	Tyne Works, Northumberland.	Apedale, near Newcastle, Staffordsh.
Coals	0,605	0,675	0,624
Cinders	0,040	0,025	0,035
Volatile Matter	0,355	0,300	0,341
	1,000	1,000	1,000

The coal which is used at the Birtly and the Tyne works, comes from the mines in the neighbourhood of Newcastle-upon-Tyne; it is sparkling, both lamellar and splinty; it does not stain the fingers, and is not crushed by a slight pressure. This coal, which is generally very pure, contains no veins of carbonate of lime or pyrites. It is very adhesive, and swells very much by the action of the heat, so that the quantity of coke it yields, exceeds that of any other coal. I have been told that at the Tyne works attempts have been fruitlessly made to use the Newcastle coal without coking it.

The coal of the Apedale works is lamellated, sparkling, and splinty; it is dull in the longitudinal fracture, and divides into small quadrangular fragments; in the cross fracture it exhibits large bands, quite smooth and very brilliant. This disposition is in the manner of small

beds, differing slightly from each other; this coal is very adhesive; it swells in the fire, and the coke it produces is light and clear, but very solid.

On a comparison of the composition of the different coals which I have mentioned, it will appear,

1st. That the coals used in the natural state in cold air furnaces are dry, very carbonaceous, and forming real antharcites.

2ndly. That the coals which, although bituminous (like those of Scotland and Derbyshire), are used in their raw state for the fusion of minerals in furnaces blown by hot air, are also dry coals.

3rdly. That the coals which are fat, bituminous, adhesive, and which change their volume and swell by the action of the fire, have hitherto required to be converted into coke, in order to be used advantageously in making iron.

Quality of the Pig and Bar Iron obtained in Works heated by Hot Air.

The Scotch Foundery pig iron, manufactured with hot air, is less valuable than that of Staffordshire. It was quoted last July, in the Liverpool market, at £4 15*s.* per ton of 2240 lbs., whilst the Staffordshire pigs were selling at £6.

This vast difference between the price of the Foundery pig iron, added to the general prejudice that pig iron made with hot air is unfit for the manufacture of bar iron, still renders many persons doubtful of the advantage of the new process. The various observations, however, which I have made, tend to prove, on the contrary, that Foundery pig iron made with hot air is superior to that for the manufacture of which cold air is used. The reduced price of the Scotch pig iron does not appear to me contrary to this opinion. Indeed, the Staffordshire pigs have always been considered the best for foundery purposes, and have always been higher prized than those made in most other parts of Great Britain. Circumstances connected with the trade may also account for the difference which exists between the pig iron of Scotland and Staffordshire; thus the manufacture of Scotland is cheaper than that of Staffordshire, and as the make is increased nearly one third by the introduction of hot air, the Scotch iron masters have considered it necessary to reduce the price of pig iron as much as they could without loss.

It is much to be wished that this important question could be decided by actual experiment. I will give, however, the different uses to which the different sorts of iron are applied in the arts,

which may perhaps prove as conclusive as experiment.

In the works near Glasgow nothing but castings are made. I have seen articles made at those works which required great strength and great ductility, viz. cylinders of steam engines, retorts for gas works, wheel-work, &c.

At Birtly, near Newcastle, and at Butterley. near Derby, I have also seen steam engine cylinders, pipes of forcing pumps, and frames for iron bridges, cast.

The Torteron furnace, which belongs to the works of Fourchambault in Nièvre, has produced, since the introduction of hot air, grey pig iron which is sold in competition with that of England.

The bar iron manufactured from pigs made in hot air furnaces is also of a very good quality.

At Codnor Park, near Derby, this iron is used in the construction of the different parts of steam engines, and in the fabrication of chains for suspension bridges; of beams and traverses for iron bridges, &c.

The iron produced in the Tyne works, near Newcastle, is converted into strong boiler plates for steam engines, gasometers, &c.

At Wednesbury the quality of the iron is also good, and is used for purposes which are intended to resist the greatest strain.

These different examples prove that by the hot as well as by the cold air process, Foundery pigs of a superior quality, and pigs fit for the manufacture of bar iron, may be procured. But it is not to be supposed, that by this system defects resulting from the nature of the coal, or of the mineral, can be corrected.

The probable Causes of the Augmentation of Heat by the Use of Hot Air.

I have mentioned several times in the course of this report, that the temperature of furnaces heated by hot air appeared higher than the temperature of those heated by cold air; all the symptoms which are usually noted in order to regulate the work of a blast furnace, combine to prove this assertion: for instance, cinder does not adhere to the top of the tuyere; the colour of the fire, in this part of the furnace, is of a brilliant white, which can scarcely be looked at; the cinder is more liquid and runs with ease; the iron is hotter and may be cast into the most delicate pieces; the quantity of mineral put into each charge is augmented in a large proportion, whilst a smaller quantity of limestone is used. This diminution of the proportion of fluxing matter is the strongest proof that can be given of the

temperature of the furnaces. It proves that the earthy particles undergo a degree of heat powerful enough to fuse them, with the addition of a small quantity only of flux. We may also probably attribute to the excess of temperature the power of using coals in their raw state, which it seems indispensable to convert into coke when the temperature of the air is not much elevated. Notwithstanding these incontestible proofs of the augmentation of heat produced by the introduction of hot air in blast furnaces, it is impossible to demonstrate its existence positively; but I think that, to a certain degree, this phenomenon may be accounted for by comparing what takes place in the furnaces from the constant influx of air, with what occurs where two liquids of a different temperature are mixed; the mixture then takes a mean temperature. This comparison appears to me just, although the furnaces are in circumstances very different to liquids, having a given temperature, because heat is constantly reproduced by the combination of carbon and oxygen: admitting this to be the cause of the augmentation of heat, it may perhaps be considered very trifling, on account of the great difference which exists between the temperature of a blast furnace, and that of the air which feeds its combustion—a difference which we have no

means of ascertaining exactly.[27] I shall presently shew that this cause is not so trifling as it may be thought. But I think there is another cause much more powerful than this, which it is impossible to estimate. It is the result of combinations which could not be produced by the ordinary temperature of blast furnaces, and which are developed by the augmentation of heat, arising from the substitution of hot for cold air. We constantly see, in our laboratories, examples of this phenomenon; substances which are but slowly and difficultly attacked by an acid of the temperature of the atmosphere, easily dissolve when the acid is slightly heated, and the combination thus formed often becomes a powerful source of heat. The working of blast furnaces may present similar circumstances: the bitumen and some sorts of gases, which could not burn at the temperature of cold air furnaces, become ignited by the slight augmentation of heat produced by the introduction of hot air: this combustion, perhaps, developes that high temperature which we observe in these furnaces; the small quantity of smoke issuing from their tunnel head, (even when heated with raw coals) as well as

27 Many chemists, and particularly M. Dumas, admit that the temperature of a blast furnace corresponds with about 1500° cent.

the colour of the flame, authorise the supposition that the bitumen, the hydrogen gas, and the carbonic acid, &c. are in great measure consumed. This supposition answers the objection, which might naturally be made, that, even admitting a certain augmentation of temperature to have been produced by the introduction of hot air into furnaces, a diminution of the consumption of fuel would not be the necessary result, since the coal saved in the furnace would be consumed in the apparatus for heating the air.

I have mentioned that the quantity of blast thrown into the furnace, might, by reason of its volume, have a strong cooling power; this body of air amounted in the Scotch works, previous to the adoption of the hot air process, to 2800 cubic feet per minute, or 124 kil. 779 in weight.[28]

The quantity of air thrown per day into the furnace thus amounts to 179681 kil. 76, or about 180 tons.

The quantity of coal, mine, and limestone, does not exceed 44 tons. Thus the weight of air is quadruple the weight of the solid materials which are thrown into the furnace. It may therefore be imagined that so considerable a mass of air, of which one fifth is of itself suffici-

[28] One cubic metre of air = 1 kil. 3.

ent for the combustion, if thrown into the furnace at 10° (which is the average temperature of the atmosphere) must produce a much greater chill, than when its temperature is 322° cent. The smaller quantity of air used according to this new process, is another circumstance which tends to diminish the cooling power of the air. In the blast furnaces in Scotland, which I have taken as an example, the quantity is reduced from 2800 to 2100 cubic feet per minute, or from 180 to 134 tons in weight, which is less by one fourth.

The influence of the introduction of air upon the heat, developed every minute, may be calculated by the combustion of coal ;[29] but it appears

29 The specific heat of water being represented by 1000, that of atmospheric air=0,2699, from which it follows that a grain of air at 322° cent. (the temperature at which air is thrown into the furnace at the Clyde) would elevate 0,733 gr. of water to 100°, supposing the air remained at 10°. And as the quantity of air thrown every minute into the furnace is 124,799 gr., the caloric or heat which results from this mass is represented by 91,463 gr. of water raised to 100°.

There is charged at the Clyde furnace 16,400 kil. of coal in 24 hours, or 23 kil. 90 ⅌ minute; a quantity which, after deducting the ashes (of the coal), the water, and gas, which escape without being burnt, amounts at the most to 20 kil. 30. The complete combustion of this quantity of carbon would raise 1 kil. 465 of water ⅌ minute to 100°. The increase of heat which would result from the increase of the temperature of the

to me impossible to appreciate the augmentation which results from the new combination, produced by the combustion of bitumen and carbonated gases, because we cannot, in the present state of science, estimate the temperature of the interior of the furnace. These few words, though they do not give any idea of the real degree of influence which hot air possesses, appear to me, nevertheless, to establish that that influence is considerable.

SUMMARY.

The details into which I have entered, concerning the principal works heated by hot air, may have obscured the chief circumstances of this process. I have therefore thought that it might be useful briefly to recapitulate them.

I. In all the works, with one or two exceptions only, a great increase of the produce, a great saving in the consumption of fuel and limestone, (as well as in the articles of labour and general charges) have resulted from the adoption of the hot air system.

air to 322°, compared with what would be produced by the combustion of carbon, would be as 92 : 1465; that is to say, one sixteenth: this would be the minimum, the quantity of oxygen not being sufficient to convert all the carbon into carbonic acid.

II. These advantages have taken place in proportion to the degree of heat, to which the air has been raised.

III. The quantity of cast iron produced has generally been greatly increased.

IV. The total quantity of fuel consumed in the blast furnaces appears to be much the same, whether they are blown by hot or cold air. At the Clyde works, 18 ton. of coke per diem were formerly used to obtain 6 ton. of pigs; 18 ton. of coal are now consumed, and 9 ton. of pigs are produced.

V. The pigs produced in hot air furnaces are generally grey, and fit for castings: the process, however, is also successful in those works, of which either the whole or a part of the pigs are converted into bar iron (Codnor Park, Tyne works, Wednesbury, &c.); it being only necessary to modify the proportions of coal and minerals.

VI. In several works, the combustion requires a much smaller quantity of hot air, than it formerly required of cold; at the Clyde works, for instance, the same blowing engine which scarcely sufficed for three furnaces, now blows four. The saving of the moving power is not in proportion to the diminution of the quantity of blast, because a certain degree of force is necessary to

overcome the friction of the air in the apparatus, and the resistance which results from its expansion. This last inconvenience is remedied by enlarging the opening of the muzzles; their diameter having generally been carried to from 3½ to 3 inches. The enlargement of the muzzles also diminishes the velocity of the current of air which is introduced into the furnace.

VII. When no diminution in the quantity of blast (as at Torteron) results from the use of hot air, it is necessary to increase the power of the engines which work the blowing machine.

VIII. The substitution of hot for cold air, in the fusion of iron mine, occasions an almost immediate change in the quality of the pigs, which become more carbonated. The charges descend slower; their descent is accelerated by augmenting the proportion of mineral.

Concerning the Apparatus.

IX. The apparatus formed by the junction of a pipe of large diameter which receives the air, and of small pipes in which the air is heated and expands, appears to me preferable to an apparatus composed of a series of large pipes; the former requires less room, is less expensive, and consumes less fuel, than the latter; besides which, in the apparatus formed of large pipes,

the temperature of the air is not uniform throughout every part, and a current of cooler air is almost always formed in the centre of the pipes.

X. In order to diminish, as much as possible, the rapidity of the air submitted to the action of the heat, and to avoid the resistance resulting from its expansion, it is requisite that the area of the small pipes be greater than that of the large pipe, which receives the air from the blowing engine.

XI. The interior capacity of these small pipes should be greater than the volume of blast, which is constantly cast into the furnace; by this arrangement, the air remains a certain time in the apparatus, and then acquires an elevated temperature.

XII. This makes it appear that the apparatus placed above the tunnel head is the least advantageous for furnaces using raw coal, as they cannot be of such dimensions as to admit of the air remaining within them any length of time. In order to remedy this inconvenience, it is necessary to pass the air again through the heating stoves, placed near the tuyeres.

Concerning the different Sorts of Coal.

XIII. Coals which would produce a large per centage of coke, dry, and antharcitous, may be

used in their raw state, even in cold air furnaces.

XIV. Coals which contain a tolerably large proportion of volatile matter, (30 to 35 per cent.) but which are not adhesive, and do not change their shape in combustion, may be used without coking, in furnaces of which the blast is heated above 300° cent.

XV. Lastly, it appears necessary to coke bituminous coal, (like that of Newcastle) even when the hot air process is used, in order to render it fit for the fusion of iron ore.

CHILCOTT, PRINTER, WINE STREET, BRISTOL.

NOTE BY THE TRANSLATOR.

Since the foregoing Report was written, considerable improvements have been made in the application of hot air to blast furnaces; not only in Scotland, but in the iron districts of Staffordshire and South Wales.

A plan is here given of the apparatus used for heating air at the Dund Ivan Works, in Scotland. It appears from this plan, that the blast is brought into the heating furnace by a large horizontal pipe, from which it is conveyed by eight smaller ones, of a semicircular form, into a second horizontal pipe; whence it passes immediately into the tuyere.

An apparatus upon the same principle has been made use of with considerable success in Wales, at the Pentwyn Iron Works; of which detailed drawings, containing a plan, and longitudinal and transverse sections are also given.

It will be observed, from the drawings, that the apparatus used at CLYDACH, in South Wales, is a modification and improvement of the plan adopted at Calder, which is described in the Report. It has been for some time in operation; and although we have not the means of stating the precise results, we understand they are very satisfactory.

The last plate represents an apparatus lately constructed, and now in use at the Dowlais Iron Works. Here the pipe, which conveys the blast from the steam engine, is doubled or folded back five times in the heating furnace; by which means a large surface of the pipe is exposed to the action of the fire. This apparatus is found to answer very well, and raises the temperature of the air to the point required, with a consumption of from 4 to 5 cwt. of coal per ton of pig iron.

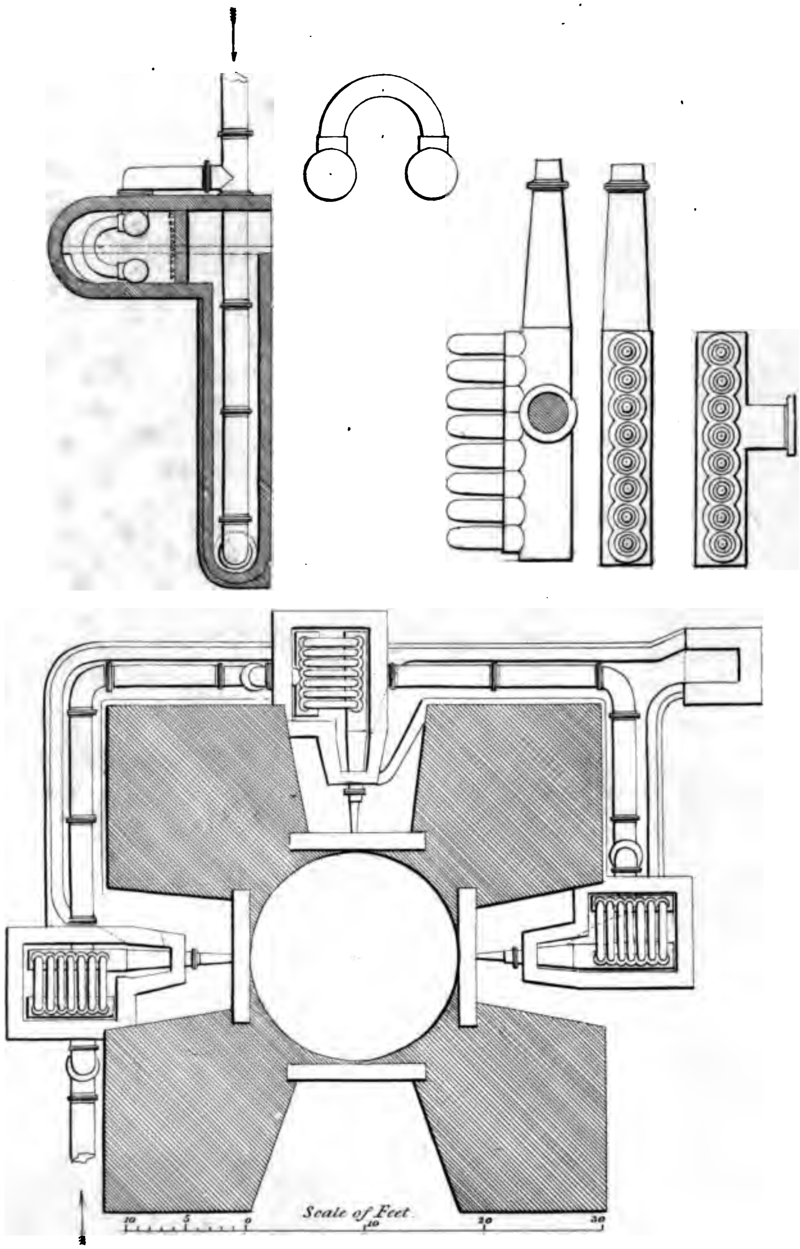
The introduction of hot blast into the Welsh Iron Works, has been certainly very beneficial. But as a much smaller quantity of coal per ton of iron was used in the blast furnaces in Wales than in Scotland, under the cold air system, the saving effected by the new process has been proportionately less.

The iron produced at PENTWYN, CLYDACH, and BEAUFORT Works, is of foundry quality.

It is not, however, considered equal in strength to pig iron, made in blast furnaces in which cold air is used: but this point has not as yet been determined by any very decisive experiments.

At DOWLAIS WORKS, the pig iron produced from hot air has been entirely used for making bars; and as the iron made there is run hot from the blast furnace into the refinery, (according to the method prescribed in Mr. Guest's patent,) some difficulty was experienced in obtaining it of the quality necessary for refining, without loss from over carbonization. This difficulty has, however, been overcome; and the bar iron made from hot air pig iron is not found to be inferior to that made from the pig iron of furnaces blown by cold air, as far as the trials yet made have enabled the proprietors of those works to determine.

J. Chilcott, Printer, 80, Wine Street, Bristol.



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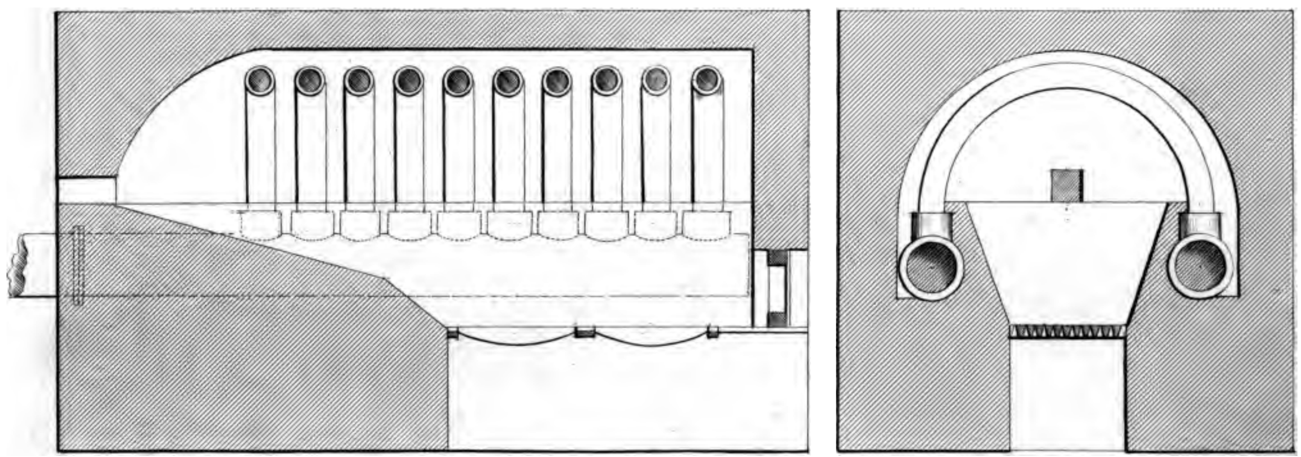
HEATING APPARATUS.

DUND-IVAN.

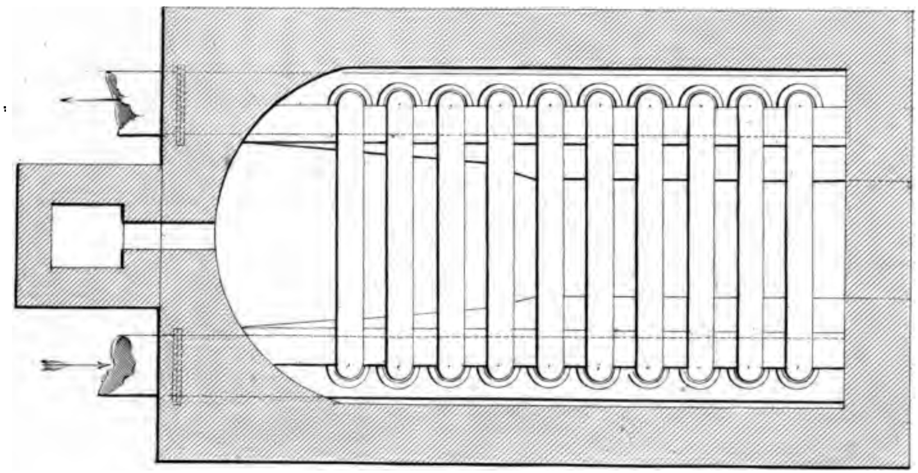
Pentwyn Iron Works.



Longitudinal and Transverse Sections of Heating Apparatus.

Scale ¼ Inch Per Foot.

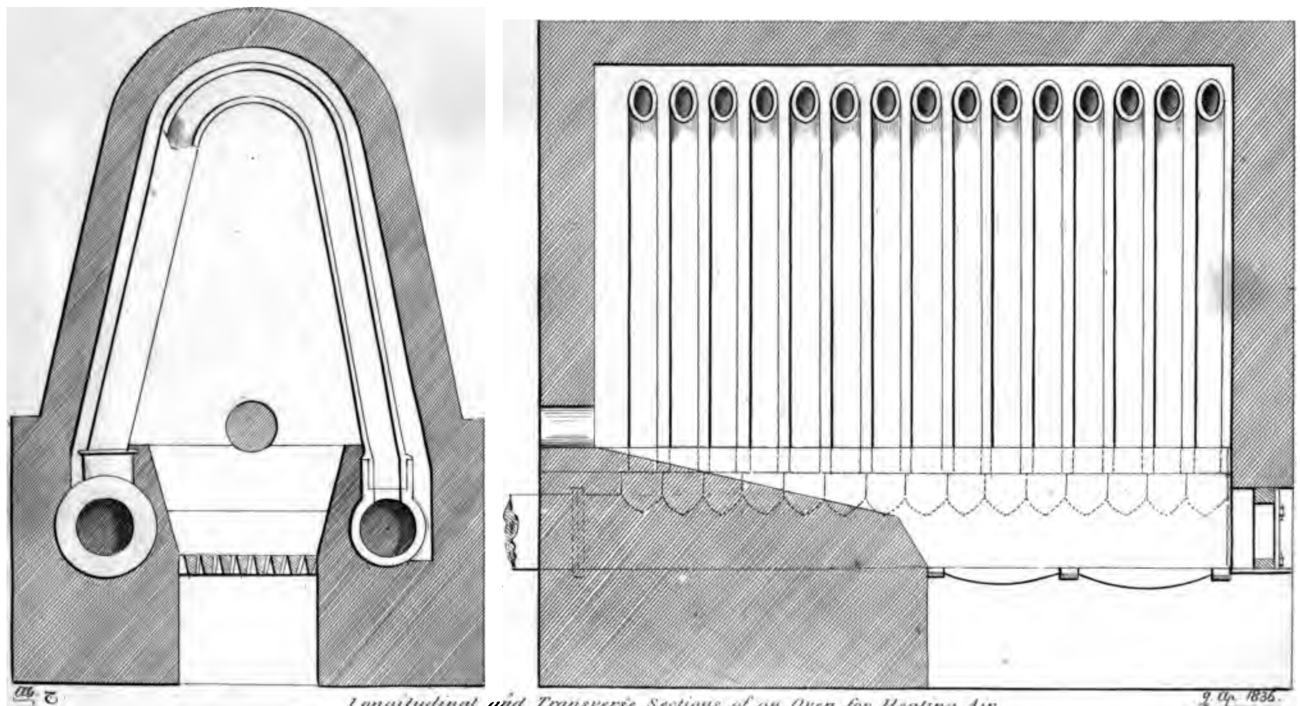
Pentwyn Iron Works.



Plan of Heating Apparatus.

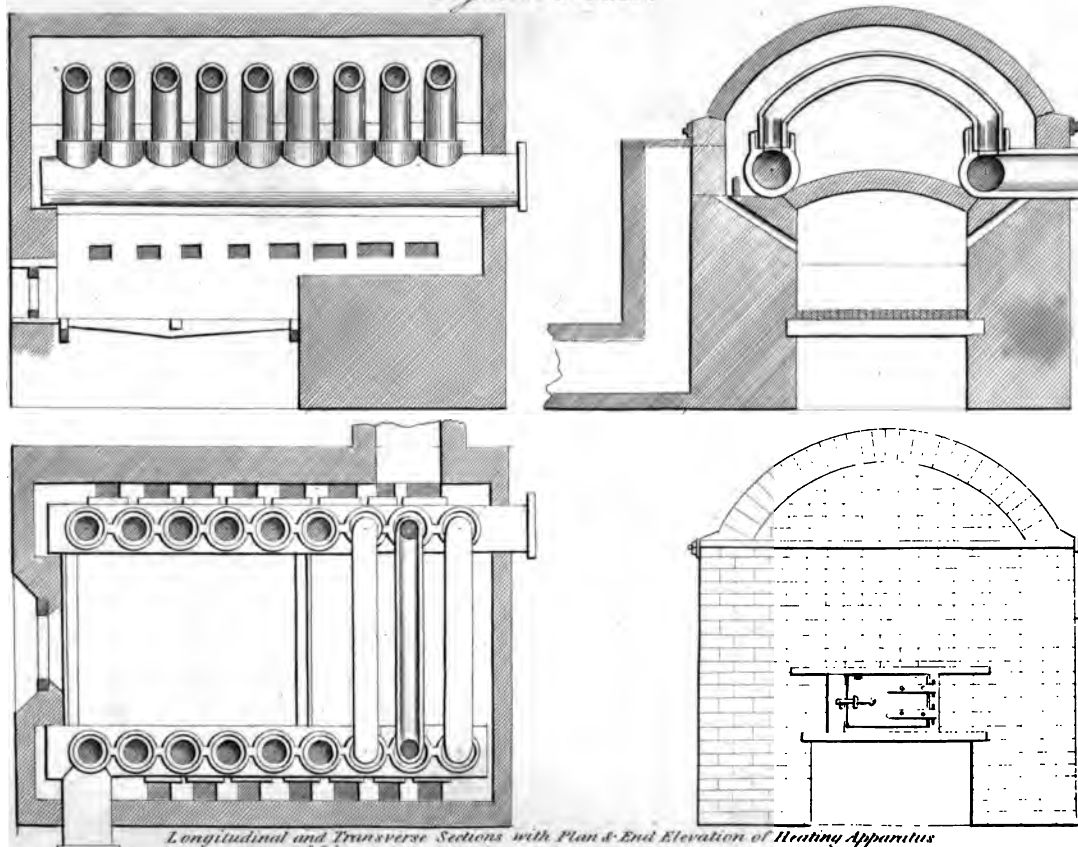
Scale ⅛ Inch Per Foot.

Pentwyn Works.



Longitudinal and Transverse Sections of an Oven for Heating Air, previous to its admission into the Blast furnace

Clydach Works.



Longitudinal and Transverse Sections with Plan & End Elevation of Heating Apparatus

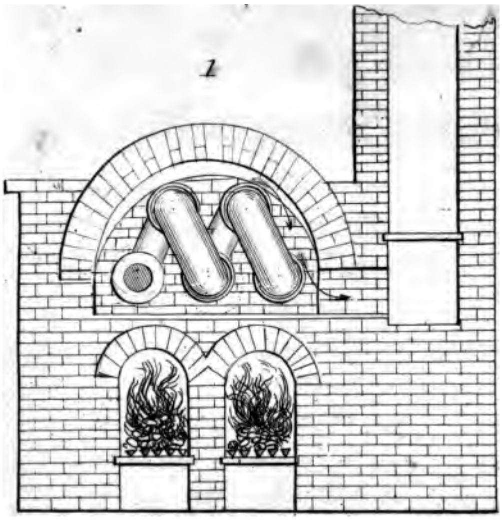
Inches | Feet

Heating Apparatus.

No. 1. End Elevation of Stove.

II. Horizontal Section of Pipes

III. Vertical Section of ...... Do.



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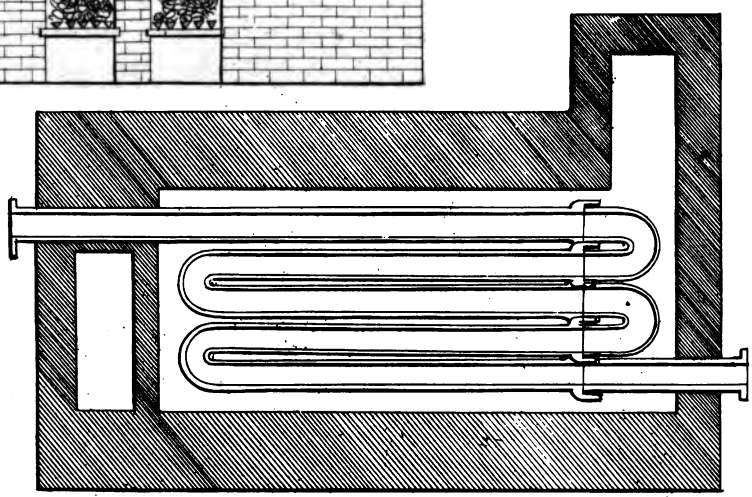

III